Predictors of mathematics attainment in hearing impaired children

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Abstract

Deaf children lag behind their hearing peers in mathematical attainment. The reasons for this delay remain unclear. Two methods were used to identify the causes for this underachievement: a longitudinal investigation of predictors of mathematical attainment, and comparison with hearing children. In order for a cause of delay to be identified, both investigative strategies must produce positive results. The deaf children must lag behind the hearing children on the measures and the same measures must predict deaf children's mathematics attainment.

The comparative study: The participants were: a) 42 hearing impaired (HI) children age range from 7;2 years to 9;1 years attending units and special schools located on eight different sites around London; b) 73 hearing children aged from 7;2 years to 8;11 years, classmates of some HI children attending a unit based in a mainstream school. A standardised maths test, a measure of their understanding of additive composition (the Shop Task), a memory scan task and tasks assessing understanding of time concepts were administered to all the children. The last two assessments were developed for the study. The performance by the HI children on standardised assessments was also compared to norms standardised on hearing populations.

The deaf obtained significantly lower scores on nearly all of the tasks. In the maths test the mean standardised score for the hearing children was 92.68 and for the deaf children was 78.31. There were also significant differences on the memory scan task – the accuracy rates were lower, memory capacity sizes were smaller and the number processing speed was slower for the deaf children. On the time concept tasks the hearing children obtained significantly more correct responses on the tasks assessing change, ability to infer and order events.

When the HI children's performance was compared to the norms of standardised assessments, a similar picture emerged. The mean Number Age was 1;1 year behind the hearing norms. The mean WISC score obtained was one standard deviation below the published mean. Raw scores obtained on the reading comprehension task were too low to be standardised. In assessments of receptive language, the HI children obtained standardised scores that were 1 standard deviation below the mean. It was concluded that all of these variables could be examined as predictor variables in the longitudinal study.

The longitudinal study: The HI children participating in the comparison study were assessed twice again over the academic year. The outcome measures were scores on standardised mathematics assessments. The predictors were demographic and medical background; intelligence, language; understanding of time; memory capacity and number processing speed; numerical skills such as counting and additive composition.

The only demographic variable consistently associated with mathematics scores was age. Analyses using fixed order multiple regression explored the relationships between the various cognitive, numerical and linguistic predictors and mathematics attainment. After controlling for age and non-verbal IQ, only three predictors remained significant: the language assessments, Shop Task, the Change and Inference Required time concepts tasks. When controlling for age, non-verbal IQ and language ability, only the Shop Task added a significant amount of variance in the equation. This equation explained 44% of the variance in a concurrent analysis and 66% and 64% of the variance in longitudinal predictions 4 and 7 months later, respectively.

Conclusions: The present study confirms that HI children are behind their peers in mathematics achievement. Explanations for this delay were sought by identifying areas where their performance is poorer than that of hearing children and predictive of their own progress in mathematics. Although the HI children achieved lower scores in the majority of the assessments in the comparative study only the language measures and the Shop Task satisfied both criteria and added a significant amount of variance in the regression equations in the predictive study. It is concluded that these may be causally related to HI children's delay in mathematics.

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Glossary of Tasks

Task	Abbreviation
Mathematics Assessments	
NFER-Nelson Mathematics tests 7 and 8 administered in Autumn1997	NFER (1)
Basic Number Test Series	Number Age
NFER-Nelson Mathematics tests 7 and 8 administered in Summer1998	NFER (3)
Cognitive Measures	
Performance scale from Wechsler Intelligence Scale for Children III	WISC
Memory capacity score in Memory scan task	Memory
Basic Number Concept tasks	
Counting to highest number	Count high
Counting backwards	Count back
Shop task assessing additive composition of number	Shop Task
Language Measures	
Individual Reading Analysis	MIRA
Oral Directions sub-test from Clinical Evaluation of Language Fundamentals – Revised	CELF-R (OD)
Sentence Structure sub-test from Clinical Evaluation of Language Fundamentals – Revised	CELF-R (SS)
Mental operations involving time concepts	
Sequential information – control task requiring no place holders	NP-HR
Sequential information –experimental task requiring place holders	P-HR
Inferring sequences form change tasks	Change
Inversion of the surface structure of event	Order

Introduction

Overview

This study proposes to identify longitudinal predictors of mathematics in order to establish possible explanations for the wide range of attainment observed in hearing impaired children. Previous studies comparing the performance of hearing and deaf children's achievement in mathematics assessments have found that, on average, hearing impaired students' performance is below that of their hearing peers (e.g. Wood, Wood, Griffith & Howarth, 1986). The present study uses two research strategies to explore the reasons for the lower achievement levels of the hearing impaired, a comparison with hearing children and a longitudinal research strategy. In order for a cause of delay to be identified, both investigative strategies must produce positive results. The deaf children must lag behind the hearing children on the measures and the same measures must predict deaf children's mathematics attainment. The predictors chosen for the study are taken from previous literature concerning hearing impaired children. Although the average performance of the hearing impaired is below that of their hearing peers, studies have also found a wide range of ability within this group. Wood et al. (1986) for instance, found that 15% of the children in their sample obtained average or above average scores in comparison to hearing children taking part in the study. This study also expects to find a wide range of scores in the standardised assessments and hopes to take advantage of this variation to identify longitudinal predictors of mathematics in a group of hearing impaired children.

The diversity of the hearing impaired as a group is vast not only in the biological factors directly related to their hearing loss, but also in the ways that hearing impairment may affect their linguistic and cognitive development. By examining a range of factors that could predict future mathematical performance, one is in fact exploring a variety of possible effects that hearing impairment may have on the development of mathematical concepts. The present study explores a number of predictors that can be classified into three groups of explanatory variables. The first category of variables includes the demographic variables associated with hearing impairment; these include the severity and causes of hearing loss. The second category of variables includes measures of the cognitive processes in the deaf population. These include measures of memory capacity and number processing speed. The third group of explanatory variables includes tasks that predict mathematical performance in hearing children. These tasks assess understanding of the number system and levels of numerical competence.

Demographic factors

Researchers have attempted to explain why the average hearing impaired child achieves lower attainment levels than the average hearing child by asking a number of questions. One line of inquiry has examined whether there is something particular about hearing loss and being deaf that hinders the acquisition of mathematical concepts, and consequently affects performance in mathematics assessments. Jensema (1975), for example, explored the existence of a relationship between demographic characteristics particular to the deaf: such as degree and cause of hearing loss, and attainment in standardised mathematics assessments. These studies have yielded few, inconclusive results because the demographic variables have explained little variance in mathematics attainment. In this study, this analysis will be repeated. The relationship between demographic variables and standardised mathematical assessments will be explored. In addition to variables previously explored, other variables will be treated as demographic characteristics. These include the severity of hearing loss when wearing hearing aids and the different types of linguistic environments a deaf child can encounter. Having established that, as in the previous studies, the demographic variables do not explain mathematical performance in this group of hearing impaired children; an alternative group of predictors can be explored.

Cognitive processes in the deaf population

Some researchers have argued that the deficit shown by the hearing impaired in some cognitive and linguistic tasks may explain lower performance in mathematics assessments. For example, researchers such as Hitch, Arnold and Phillips (1983) found that the number processing skills of the hearing impaired were slower than those demonstrated by comparable hearing participants. These researchers suggested that the slower response times may explain why hearing impaired children perform less well at mathematics. The researchers did not test this hypothesis directly; which is based on the implicit assumption that all hearing impaired participants obtain lower mathematics attainment levels than their hearing peers and so would all consequently lack proficiency in the skills required to complete cognitive tasks as efficiently as the hearing participants. In fact, some hearing impaired children achieve scores that are above these low levels. The present study includes a range of tasks that assess skills on which the hearing impaired have previously been shown to demonstrate a delay in comparison to hearing children; these include tasks assessing language, number processing, and understanding of time concepts. The relationship between these tasks and mathematical attainment are examined directly to establish the existence of a causal relationship between performance deficit in the predictor tasks and mathematics attainment.

Predictors of numerical development in hearing children

The two previous groups of predictors described above assume a causal relationship with mathematics attainment. In other words, there is something inherent about hearing loss that causes lower performance in mathematics; there is a direct relationship between inadequate or inappropriate cognitive processes and poor mathematics performance. An alternative approach for examining the relationship between mathematics and hearing impairment is to examine whether the relationship is indeed causal or whether hearing impairment presents a risk factor in the acquisition of numerical concepts. This ‘risk factor’ hypothesis suggests that hearing impaired children can learn about numerical concepts in the same way as hearing children, but that some children may experience a delay in the acquisition of these concepts. The ‘risk factor’ hypothesis has not been explored previously. In the present study the hypothesis is addressed with the presentation of the third group of predictor variables, based on research with hearing children. The predictor variables include tasks that have been found to be predictors of numerical attainment in hearing children, such as the Shop Task (Nunes, Miranda & Silva, 1991) and counting ability.

Organisation of the thesis

Chapter one explores the theoretical impact of hearing impairment on general cognitive development. This is achieved firstly by describing the etiology of hearing impairment, the different types of hearing loss and the different possible causes. Research concerning the potential impact of hearing impairment on children's linguistic and cognitive development is described. Throughout the chapter, issues surrounding the educational provision for hearing impaired children are raised.

Chapter two examines the mathematical attainment of hearing impaired children. Research comparing the attainment of hearing and deaf students is presented. The aim of the chapter is to review research that has examined the possible explanations for these differences. Having established that previous research has provided few explanations for the variety in mathematics attainment, the chapter then asks whether a developmental approach could do so. By examining the development of numerical concepts in hearing impaired children, with particular reference to parallel research with hearing children, a new framework for examining potential predictors of mathematical attainment is developed. The chapter identifies possible sources of difficulty in the acquisition of numerical concepts that the hearing impaired child may face, in comparison to their hearing peers. The plan for the main studies is presented at the end of the chapter.

Chapter three presents the comparative study. The performance of the hearing impaired and hearing children are compared on the mathematics assessment, the memory scan task and the time concepts task. In addition to this, the performance of the hearing impaired on standardised assessments is compared to the published norms. In this way it can be established whether the hearing impaired are behind and on which assessments. The purpose of this is to establish on which tasks can be used as variables in the predictive study.

Chapter four presents the predictive study which explores relationships between the various predictor variables and mathematical attainment. The aim of this chapter is to establish the major predictors of mathematics attainment in a sample of hearing impaired children. The first set of predictor variables is the demographic variables.

Following this, the concurrent and longitudinal relationships between standardised mathematics scores and the predictors taken from research about the cognitive processes of the hearing impaired and about numerical development in hearing children are explored.

The final chapter summarises the results of the predictive studies. In the conclusion, the educational implications of the study are discussed. Recommendations for further research are also presented.

1. Background of Deaf population

The present chapter describes the different types and causes of hearing loss and investigates the possible consequences of hearing impairment on linguistic and cognitive development. Hearing impairment can occur for a number of reasons and its consequences can vary from person to person. In the present study these variations are treated as demographic variables so the purpose of the present chapter is to establish which of the demographic variables associated with hearing impairment will be explored in relation to mathematical performance.

The participants of the present study are children, and for this reason, the causes and consequences of hearing impairment that are pertinent to children's linguistic and cognitive development are focused upon here. The following section describes the etiological aspects of hearing impairment. The second section describes the linguistic development of hearing impaired children. Lastly, theories concerning the cognitive development of deaf children are described and explored.

1.1 Etiology of hearing loss

The different causes of hearing impairment result in different 'types' and 'degrees' of hearing loss. The degree of hearing loss describes the severity of the impairment. The type of hearing loss refers to the location of the dysfunction in the ear. After a brief description of the ear, the type and severity of hearing loss are described in more detail.

1.1.1 Anatomy

There are three sections of the ear; these are the outer, middle, and the inner ears. The outer ear is made up of the pinnae and the outer canal. Sound waves travel along the outer canal towards the entrance of the middle ear. The middle ear covers the area from the ear drum to the oval window, and its function is to transform sound waves into vibrations and transport (or conduct) the vibrations to the inner ear. Sound waves are transformed into vibrations when they hit the eardrum causing the first of the three bones (malleus) to vibrate as well. The three bones (the ossicular chain) are connected so that vibrations in the first bone cause vibrations in the next. In this way the sound is transported to the oval window, the entrance to the cochlea. The cochlea and the nerves from the cochlea to the brain constitute what is called the ‘inner ear’. Vibrations on the oval window move a liquid inside the cochlea which, in turn, activate tiny hairs located all the way along the inside of this tube. Each of these hairs is attached to nerves and covers a certain frequency of sound. As the liquid brushes the hairs, the nerve endings are stimulated sending a message to the brain.

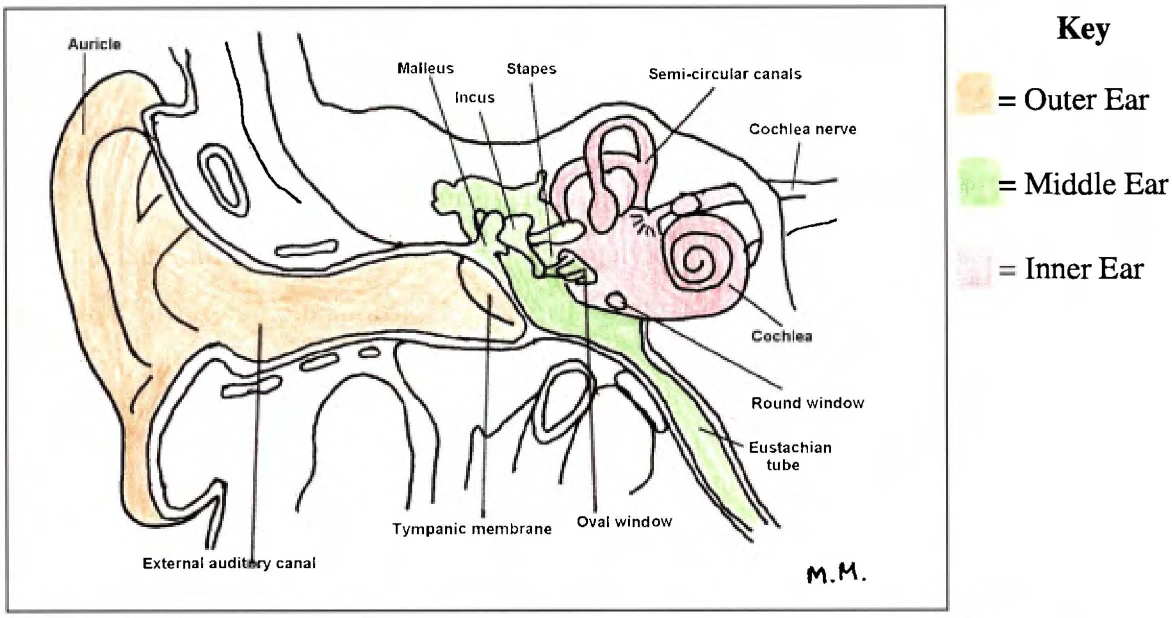


Figure 1.1. Cross-section diagram of the ear.

1.1.2 Types of hearing loss

There are two types of hearing loss, ‘conductive’ and ‘sensori-neural’. Generally, conductive loss is less severe but more prevalent. Sensori-neural loss can be more severe but its incidence is less frequent (Gibben, 1993).

Conductive hearing loss occurs when sounds are prevented from passing through the outer and middle ear to reach the inner ear normally. According to McCormick (1995), 6% of all children will have an episode of significant hearing loss (above 20 decibels) at some stage. Most incidences develop in children below the age of 4 years and they rarely manifest themselves in children above 8 years. Approximately 80% of babies will have middle-ear fluid within the first year of life and the majority will require no treatment.

Hearing losses arising from conductive problems are often caused by common and temporary illnesses such as congestion of the middle ear cavity with fluid (otitis media) that may even occur during a cold. Less common but more permanent causes of conductive hearing loss include perforated eardrums or abnormalities in the ossicular chain that vibrates to transport the sound into the inner ear.

Gibben (1993) states that sensori-neural hearing loss often results in a more severe or even a profound loss. However, the incidence of this type of hearing loss is more rare. McCormick (1995) estimated that severe to profound hearing loss only affects one to two babies per thousand births. This incidence rate is greater in babies born in special care units, who are ten times more likely to be affected than babies who have births with no complications. The majority of these children will suffer a sensori-neural hearing loss.

Sensori-neural losses are generally a result of problems in the inner ear and can be caused by complications located in two areas, the cochlea and the auditory pathway. Abnormalities in the first area, the cochlea, causes what are sometimes called 'peripheral' hearing loss and involves damage or abnormalities to the nerves in the inner ear. Abnormalities include the malformation of the cochlear membranous system (Northern and Downs, 1991).

Abnormalities in the auditory pathway are referred to as 'central' or retrocochlear hearing loss. This is a very rare cause of hearing loss in children (Mason, 1993). Damage can result from a tumour in the brain stem or in any of the auditory cortex areas of the brain. Malformations of the nervous system, like that of cerebral palsy, could also cause a retro-cochlear hearing loss. Damage to the inner ear can also be acquired later on in childhood leading to a profound or total hearing loss. McCormick (1995) identified meningitis as the most common cause of acquired hearing loss.

As far as is known there are no differences as a result of the type of hearing loss on the academic achievement Those children with fluctuating conductive loss are considered to be at risk academically because their loss is often undiagnosed. This type of hearing impairment is usually less severe and sporadic. Children with this impairment are often thought to be 'lazy' or 'daydreaming' because they are not following what is going on the classroom (Gibben, 1993). In general, however, those children that require and receive more educational and linguistic support are children with more severe hearing impairments caused by a sensori-neural hearing impairment or a sensori-neural hearing loss with a conductive overlay.

1.1.3 Causes of hearing loss

As well as an initial indication of the type of hearing impairment the child may have, the cause of hearing impairment is also an important source of information regarding the likelihood of a presence of a learning difficulty in the child. The development of the brain and nervous system in the womb could be affected by number of factors. These include: maternal rubella; birth trauma such as rhesus incompatibility or lack of oxygen during birth; and infections in the brain such as meningitis all of which are associated with intellectual deficits and would consequently affect the child's educational career. The following section describes those causes of hearing impairment that are most common in children.

1.1.3.1 Deafness from birth (congenital hearing loss)

Children with congenital hearing loss are those born with a hearing impairment. There are broadly two causes for congenital hearing loss, 'hereditary' and 'acquired'.

The causative factors in hereditary hearing loss are present in the fertilised ovum in other words, they are present in the parental chromosomes. The inherited genes may cause deafness alone, or may be part of a combination of abnormalities. When particular combinations of abnormalities are found to recur they are often known as 'syndromes'. One such syndrome is Usher's syndrome. With an incidence of 1 in

20,000, this autosomal recessive disorder is a combination of abnormalities, which include sensori-neural hearing loss together with a progressive blindness. In addition to this, there is sometimes a speech impediment over and above that associated with hearing impairment (Sparks, 1984).

Those congenital losses not caused by hereditary factors are usually caused by factors that act on the foetus while it is developing. These are called ‘acquired’ hearing losses. Examples of factors that act on the foetus could be illnesses or viruses such as maternal rubella occurring during the first and second trimesters of pregnancy. Another virus which acts on the foetus during pregnancy but that does not necessarily result in congenital deafness is cytomegalovirus (CMV). There have been cases where the new-born baby has been found to be infected with the virus, but the hearing loss develops at a later stage.

1.1.3.2 Birth Injury

Difficulties during the delivery of a child could result in hearing loss in the child. One problem that could occur is that the mother and child have incompatible blood types. The most common incompatibility is the presence of Rhesus protein in the blood of the mother but not the baby or vice versa.

1.1.3.3 Acquired hearing loss, post-natal

The most common causes of post-natal hearing loss are serious illnesses such as meningitis, mumps or measles that may result in hearing loss in one or both ears. A severe accident particularly to the head may also cause post-natal hearing loss.

1.1.3.4 Unknown

A large percentage of hearing loss in children occurs in families with no previous incidence of hearing loss. According to McCracken and Sutherland (1991) in 30 to 60 percent of all cases of sensori-neural deafness, no causes can be pin pointed.

Changes and advances in medicine have had an impact on the incidence of causes of hearing loss. One example is the reduction, mostly in the Western world, of those hearing losses related to problems at the time of the delivery, such as blood incompatibility. Table 1.1, adapted from Blennerhasset, Strohmeier and Hibbett (1994), reports the causes of deafness in a sample of students from a deaf residential school taking part in a study of the validity of Raven's progressive matrices. They also report the number of subjects in another, earlier study by Brown (1986). Both populations of hearing impaired children were from the United States of America.

Table 1.1 shows differences between the two studies. The first difference is the identification of the CMV in the later study but not in the earlier study. This is because the discovery of the virus is relatively recent. The incidence of rubella usually follows a cyclical pattern due to the nature of epidemics. Owing to recent vaccination programmes, the number of cases of hearing loss caused by rubella is decreasing. The number of unknown causes still remains high.

Table 1.1. Percentage of causes of hearing impairment described in two studies (adapted from Blennerhasset, Strohmeier and Hibbett, 1994)

Cause	**Brown (1986)†**	**Blennerhasset, Strohmeier and Hibbett (1994)**
	subjects born 1966-1982	subjects born 1971-1983
Hereditary	13.4	19.8
Meningitis	8.4	8.5
Maternal rubella	8.7	6.6
Prematurity	4.2	1.9
Otitis Media	3.5	1.9
CMV	Not reported	1.9
Pregnancy complications	3.6	0.9
Other	20.3	18.9
Unknown	42.5	39.6

† The total percentage is over 100 because some of the reported causes were multiple

1.1.4 Severity of hearing loss

As well as identifying the cause of hearing loss, diagnosis also involves assessing the degree of hearing loss. A single cause could lead to varying degrees of severity of hearing loss in one or both ears. With an increasing severity of hearing loss the child hears less, and consequently requires increasing levels of amplification and educational support. There is an assumption that a causal relationship exists between the severity of hearing loss and the child's academic achievement because a more severely deaf child will have less access to oral information. This assumption has to be addressed, and the relationship between mathematical ability and severity of hearing loss will be explored.

There are different categories of hearing impairment that express the range of severity of hearing loss. The categorisations used to describe each level of hearing loss in order of increasing severity are (cf. Katz, 1978): mild (27-40dB), moderate (41-55dB), moderate-severe (56-70dB), severe (71-90dB), and profound (91+dB). Taylor and Bishop (1991) refer to the following guidelines: mild (<40dB), moderate (41-70dB), severe (71-95dB), and profound (95+dB). It should be stressed that these are when the hearing thresholds begin. For example, a person with a moderate hearing loss will begin to hear sound at around 41dB. Anything quieter than this will not be heard without some form of amplification such as a hearing aid.

The levels of audition, and the severity or 'degree' of hearing loss are established by examining a pure-tone audiogram. This involves the patient wearing a set of headphones through which a range of pure tones are played in a range of pitch and loudness. The task is to acknowledge whether the tone being played is heard. The audiogram test covers the frequency range of 125 Hertz (Hz) to 8000 Hz because these are the frequencies covered by speech. Once the responses across different frequencies have been plotted on the audiogram, diagnosis of the severity or the 'degree' of a person's hearing loss can be achieved.

Table 1.2 shows the range of sounds that can be heard at different ranges of loudness. So, a person with a moderate hearing loss may be able to hear a dog barking and loud music, but they may not hear normal conversation or bird-song without amplification.

Table 1.2. Range of sounds that can be heard at varying levels of decibels (adapted from McCracken and Sutherland, 1991)

Decibel level (dB)	sounds heard at this level
0	
10	leaves rustling on a branch
20	a bird singing
30	whispering at 1 metre
40	
50	bank of a stream
60	normal conversation
70	dog barking
80	loud music
90	lorry revving at 5 metres
100	
110	pneumatic drill at 1 metre
120	jet plane taking off
130	
140	Threshold of pain

Definitions of the severity of hearing loss also depend on the child's needs, in other words, the extent of educational support required. Moores (1996) described the functional categorisation of educational placement based on the degree of hearing loss. These categorisations are variable and provide an idea, or a guide, of the educational needs of hearing impaired children at varying degrees of hearing loss.

Table 1.3. Severity of hearing loss as defined by a person's need of assistance (adapted from Moores, 1996)

Level of hearing loss (dB)	**Requirements of the individual**
35-54	The individuals in this category do not routinely require special class/school placement; they do routinely require special speech and hearing assistance.
55-69	These individuals occasionally require special class/school placement; they routinely require special speech, hearing and language, assistance.
70-89	The individuals in this category routinely require special class/school placement; they also routinely require special speech, hearing, language and educational assistance.
90 and beyond	The individuals in this category routinely require special class/school placement; they also routinely require special speech, hearing, language and educational assistance.

As can be seen, those with a more severe hearing loss generally require more assistance than those with less severe hearing loss.

1.1.5 Hearing assistance

Once the child has been diagnosed with a hearing impairment, a hearing aid is suitable to the levels of loss are given to the child. In Table 1.3 this is referred to as 'Hearing assistance'. It has been argued (e.g. Meadow, 1978) that the levels of hearing loss when aided should also be noted because it gives an indication of the oral information that the child can make use of in the classroom. With this information the relationship between the aided hearing loss and educational attainment can be explored.

There are two types of hearing aids, ones that are worn in the ear (body- or post-aural aids) and those which are worn with cochlear implants. Those worn in the ear are more common because the development of cochlear implants is relatively recent. Both types of aids amplify sound, however those wearing post-aural aids can also have additional amplification support through a system that works in conjunction with the hearing aid. This is particularly useful where there is a lot of background noise. A hearing aid does not discriminate noise like the normal ear can and all noise is amplified, these support systems help to amplify the voice of the person, such as the teacher talking without too much of the surrounding sound being heard as well. There are two systems, one that works with electromagnetic induction (the ‘loop’ system), and the other that works through direct input into the hearing aid. In both cases the person talking wears a microphone, and the aid wearer has an additional radio receiver from which the sounds in the microphone are amplified. Although these systems can be beneficial in a classroom setting, they are not always appropriate to all situations. On occasions where there are group or class discussions, a child across the classroom could make a contribution, but because they are not speaking into the microphone, the aid wearer would miss this contribution.

Although hearing aids amplify sound, this does not necessarily mean that hearing impairment is corrected, the sound the aid wearer receives is imperfect and can be distorted. In cases where the hearing impairment is very severe, there may not be aids powerful enough to amplify the sound to a sufficiently high level. The extent to which the hearing aid could be of use to a child is dependent on a number of factors. These include the degree of unaided hearing loss and the amount of residual hearing the child has (this is the amount of useful hearing the person has for comprehending speech). In addition, the frequencies over which the hearing loss occurs and the amount of training in skills such as lip-reading the child has received also impact the benefit that can be gained from wearing a hearing aid. This could vary from child to child, even if the degree of unaided hearing loss is the same. The levels of residual hearing and the specific training the child has received are difficult to measure and assess. However, a measure of the amount of hearing of which the child can make use is possible and is desirable. This information is not always provided by the hospitals, but wherever possible, this information has been included as a demographic variable and the relationship with mathematics attainment is examined.

1.1.6 Summary

At the initial diagnosis of a hearing impairment there are already a number of factors that can vary from child to child. The cause of hearing impairment affects the type of hearing loss and the possibility of additional learning difficulties. The type of hearing loss will not be examined because the children in the present study all had sensori-neural losses with or without a conductive overlay. The severity of hearing loss is also an important factor and is examined because the extent of assistance required depends on the severity of the child's loss. Linguistic development is also related to the severity of hearing loss. The linguistic development of children is examined more closely in the following section.

1.2 Development of communication in hearing impaired children

Harris (1978) notes that much of the early research with the hearing impaired viewed the essential problems as having a medical origin. Treatments focused on providing medical care and amplification systems such as hearing aids. Today, however, the focus has moved away from viewing hearing impairment as merely a medical problem to one that acknowledges the difficulties in communication that the hearing impaired encounter. Harris (1978) goes on to raise the issue that the primary impediment for hearing impaired children is difficulties they experience in acquiring the majority language of society: namely the oral, spoken language. Parents of the hearing impaired child have to make choices about the communication environment that their child will grow up in. They can choose an oral environment where their child is likely to experience a delay in their linguistic development, possibly leading to an academic delay. Or the parents can choose a signing environment where their child can develop linguistically and academically at a normal rate in comparison to their hearing peers, but in a minority language. Given that 90 percent of hearing impaired children are born into families where they are that only hearing impaired member. The choice of a signing environment would have implications for the way the whole family communicates, family members may have to learn sign language themselves in order to communicate with the deaf child (see for example Fletcher, 1987). Because the communication environments directly affect the type of schooling the hearing impaired child will receive and the academic career of the child, they are treated in the present study as demographic variables that may affect the mathematical attainment of the child. The following section presents research examining the linguistic development of hearing impaired children in the different communication environments.

1.2.1 Communication Mode

Paul and Quigley (1990) describe the different modes of communication and the different languages that a hearing impaired child can be exposed to. The modes of communication can either be manual or oral (or a combination of both). The languages a child in Britain can be exposed to are English and British Sign Language (BSL).

BSL is a manually signed language, with its own grammar and structure and which is signed without speaking. English is the spoken language, there are also signed representations of English, and the most commonly used is schools in Britain being Signed Supported English (SSE). SSE is English that is spoken and signed simultaneously, although the signs used are often those from BSL, the grammar and structure of the language is English.

Schools in Britain generally teach using oral methods or using Total Communication methods. Total Communication involves teaching the children through a combination of signed and oral modes together with other visual cues to aid communication. There are also schools that teach in BSL. The choice of which communication methods to use with a hearing impaired child is often made by the parents. The choice is often made on the basis of the child's requirements (for example, whether there are additional learning difficulties or the severity of the hearing loss) and on the personal preference of the parents. The type of school that the child is sent to will often be a consequence of the choice made about communication and is dependent upon the availability of schools and facilities within education authorities. There is a wide range of severity of hearing impairment, and the wide range of communication resources available to the child reflects the variety of needs.

1.2.2 Oral language development in deaf children

The oral linguistic development of hearing impaired children is typically delayed from that of the normally developing hearing child. However, oral language is not necessarily absent, there is a range and variety in linguistic (and oral) abilities in this population. This has been found in studies which have demonstrated that some deaf students have an awareness of rhyme in lists of words (Conrad, 1979), and demonstrate the use of phonological codes when reading and writing (Leybaert, 1993). Marschark (1993) points out that it is inaccurate to say that hearing impaired children lack oral language skills, but that it is more accurate to note that '...the language skills of deaf children, as a group, are clearly more variable than those of hearing children...' (p. 167). Nevertheless, linguistic development is affected by hearing impairment from the early stages of the child's life.

Deaf babies have been found to babble in the pre-linguistic stage of language acquisition. This stage has been examined in more detail by looking more closely at the different types of vocalisations. A development in babbling and the types of vocalisations made in this stage has been found. Hearing children in the first two months produce 'quasi-vowels' in what is called the phonation stage. Infants then start to coo from the ages of 2 to 3 months. The range of sounds produced increases to include true vowels and grunts from 4 to 6 months. The last stage of the babbling is called the canonical stage, where the infants produce combinations of consonants and vowels -- 'gaga', 'mama' (Marschark, 1993).

Stoel-Gammon and Otomo (1986) carried out a longitudinal comparison of hearing and deaf infants' babbling to examine whether there were differences in type and development of babbling. This comparison investigated the role of audition in early linguistic development, and examined whether the vocalisations of deaf babies were qualitatively different to hearing babies given that they cannot hear sounds to copy them, and do not receive feedback from the sounds they produce. The vocalisations made by deaf infants were compared to the hearing infants. Initially, comparisons were made on the basis of hearing status: ‘hearing’ or ‘deaf’. Comparisons between the subjects made later considered the degree of hearing impairment in the deaf infants.

The vocalisations of normally developing hearing children aged 4 months were observed for 14 months until they were 18 months old. A group of 11 moderately to profoundly deaf children were also observed for an average period of 7 months. The ages of the hearing impaired children at the beginning of the study ranged from 4 to 21 months. The ages of the same children at the end of the study ranged from 13 to 28 months. The vocalisations of these two groups were compared. It was found that although both groups of infants did vocalise, there were differences between the two groups. The hearing group of babies displayed a significant increase of variety of consonantal sounds over the period of observation, whereas the deaf infants displayed a significant decline of this type of vocalisation over the same period. The differences between the two groups were most marked at around 8 months when the hearing infants were producing canonical babbling. Analysis that considered the degree of hearing loss revealed that the divergence between the deaf and hearing infants was most pronounced if the infant was severely or profoundly hearing impaired, and less marked in those infants with moderate hearing losses.

Oller and Eilers (1988) also compared the vocalisations of hearing and deaf infants to examine whether the deaf babies followed the same pattern of linguistic development as hearing children. They also investigated the impact of early amplification on oral linguistic development. The hearing impaired infants were all severely to profoundly deaf and had received early amplification and speech stimulation. Comparisons revealed that, whereas the hearing infants demonstrated a typical onset of canonical babbling at around 7 months, the deaf infants did not begin canonical babbling until 11 to 25 months. The deaf infants also showed a lower proportion of babbling in their vocalisations than the hearing infants did. The study indicates that although the deaf babies took longer than hearing babies did to develop canonical babbling, they still go through the same stages of linguistic development.

Studies that explore the acquisition of first words indicate that the deaf child's delay in the linguistic development continues into the later stages. Gregory and Mogford (1981) for example, report that hearing children develop their first word 5 months earlier than deaf children, and move from one to ten words in about a month. Deaf children, on the other hand, take 7 months to make the same transition. Comparisons between the deaf and hearing in vocabulary size also show a hearing child's advantage over the deaf child. Herman (1987) estimated that most children encounter new words by the tens of thousands per year, and learn thousands of them. Di Carlo (1964) quoted that the 'typical (deaf) 5 year old has approximately 25 words'. Silverman-Dresner and Guiulfoyle (1972) examined the vocabulary scores of over 13, 000 deaf children aged 9 to 17 years. The subjects were shown words which were familiar to normally hearing 6 to 11 years olds, and found that 8 to 9 year olds recognised 18 out of 7 300 words. The 16 to 17 year olds recognised around 2 500 (35%) of the words (in Densham, 1995).

There is evidence that, generally, the deaf child is not only delayed in their linguistic development but that speech production can be qualitatively different. This can result in variation in clarity of speech amongst deaf children. The age at which the hearing impaired child first receives amplification has been found to be significantly related to speech intelligibility. Those children receiving earlier amplification, having better speech intelligibility than those receiving amplification later (Markides, 1983, 1986). Markides (1986) also found that those children who had received aids before the age of 6 months had speech that was significantly superior to all the other groups.

The different studies seem to indicate those children who are more likely to successfully achieve oral language will be those with less severe hearing losses that have received early amplification and training. In light of this, the age of the child when first receiving medical attention has also been included as a demographic variable. Although there is evidence (e.g. Paul and Quigley, 1990) to show that some severely hearing impaired children can acquire oral linguistic skills successfully, there are some children who are not so successful. It may be that for these children signing could be a more appropriate mode of communication.

1.2.3 The acquisition of Sign

1.2.3.1 Children of deaf parents

Infants born to deaf parents are exposed to sign language in the same way as hearing children of hearing parents are exposed to spoken language. Research has examined the language acquisition of infants born into a signing environment to establish whether the same stages of language acquisition can be identified in the development of sign language.

Studies suggest that the pattern of acquisition of sign language in the deaf home is much the same as in a hearing home (Kyle, 1988). There is evidence of manual babbling (e.g. Prinz & Prinz, 1979; Petitto & Marentette, 1991). Petitto and Marentette (1991) videotaped the progression of manual babbling of two deaf children of deaf parents and three hearing children of hearing parents from 10 to 14 months. Using criteria which was parallel to studies examining vocal babbling, Petitto and Marentette (1991) found that both the deaf and hearing infants produced manual activity which were devoid of meaning but could be interpreted as having attributes of American Sign Language (ASL), such as handshape. However, only the deaf children appeared to progress through the stages described in vocal babbling, moreover, their manual productions were more complex and varied than those of hearing children. By 14 months more than 60% of the deaf infants' manual activity was described as manual babbling compared to 4 to 15% of the hearing children's productions. As well as this there is evidence indicating that signing children show a consistent hand preference beginning with their first words (Bonvillian & Richards, 1993).

The rate of increase in vocabulary size in sign also seems similar to the rate in spoken words. Folven and Bonvillian (1991) examined the number of signs produced by hearing children of deaf parent. Based on parental diaries and reports, it was found the first words were found to emerge at around eight months, with the vocabulary increasing to 10 words by around the age of 13.5 months. The types of signs were also examined. Orlansky and Bonvillian (1984) categorised the types of signs produced by the children (13 hearing children of deaf parents) into 'iconic', 'transparent' and 'arbitrary'. Iconic signs look like the objects they are referring to, transparent signs look like part of the object being referred to and arbitrary signs do not look like the objects being referred to. It was expected that the first signs to be produced would be the iconic signs together with pointing gestures. However, this was not observed, the signs produced by the children were evenly distributed between the three groups of sign classifications. The same pattern was found in the Folven and Bonvillian (1991) study.

Types of interactions between the deaf mother and her child have also been examined. There is evidence of a signing 'motherese', Japanese deaf mothers were found to use signs at a slower tempo with their deaf infants than when communicating with their adult friends (Masataka, 1992). The mothers also tended to repeat the same sign frequently and the movements of the sign were exaggerated. This has parallels with the hearing mother's speech to her hearing infant. Thus indicating that not only does the pattern of language acquisition appear to similar between children learning sign as a first language and hearing children, but also that the types of interactions between carer and child appear to be similar despite the different communications modes.

1.2.3.2 Deaf children of hearing parents

As mentioned previously, 90% of hearing impaired children are born to families with hearing parents. Awareness about sign language has increased and parents of deaf children have started to learn sign because of their child's impairment (e.g. Fletcher, 1987). It appears that studies of sign language acquisition focus only on (deaf and hearing) children of deaf parents. There have, however, been studies concerned with the development of gesture in hearing impaired children of hearing mothers. Goldin-Meadow and Mylander (1993) followed the development of 10 severely to profoundly deaf children, aged 1 year 4 months to 4 years 1 month at the beginning of the study, for about a year. None of these children were exposed to sign at home, and all eight of those who were at schools were in oral education. Videotaped sessions of the mother and child playing at home were analysed for the gestures used by the mother and the child. The mothers and not the fathers took part in the study because they were the primary carers.

The gestures used by the children were analysed in two ways: firstly the development of the gestures over the study's time period was noted; and secondly they were compared to the mother's gestures. At the beginning of the study all but two of the children were using two-gesture sentences. During the course of the study the remaining two children produced two-gesture combinations at the ages of 1 year 6 months and 2 years 5 months. These ages are comparable to the production of two word sentences in hearing children. The eight other children progressed from two gesture productions to more complex gesture structures during the course of the study. The mothers, on the other hand, produced mainly single gestures and showed use of the two gesture strings after their children had been observed to use them. When the mothers did use strings of gestures, they did not show the structural regularity demonstrated by their children. The strings of gestures produced by the children, according to Goldin-Meadow and Mylander (1993), resembled early sentences in the linguistic development of oral and signing children.

The hand-shapes produced by one of the children and the mother were also compared. It was found that the repertoire of hand-shapes displayed by the child included those used by the mother in addition to many other hand-shapes. This was interpreted as demonstrating the child's ability to go beyond the information that the mother had provided and generated new gestures (cited in Goldin-Meadow and Mylander, 1993). However, although the mother was the primary carer, the child could have been exposed to other people using different sorts of gestures and hand-shapes and may indicate a repertoire composed of the gestures of many people.

The findings from the above study and others by Goldin-Meadow (cited in Goldin-Meadow and Mylander; 1993) suggest that children play an active role in the acquisition of language, and that they are capable of generating grammatical systems and applying rules which they have not been exposed to.

1.2.4 Age at onset of hearing loss

The hearing impaired children in the studies above were born with hearing impairments, or had suffered a hearing loss within the first few months of their lives. The impact of hearing impairment on linguistic development has also be seen in comparisons of those suffering with a hearing impairment before and after the third or fifth year of their lives (the cut-off point varies from study to study). Those who suffered a hearing impairment before this age are categorised as having a 'pre-lingual' hearing loss. Those suffering from a hearing loss after the cut-off point are categorised as having a 'post-lingual' hearing loss. In other words, they suffered a hearing loss after normal linguistic development. The impact of the time of onset of hearing impairment has been examined by comparing 'post-' and 'pre-' lingual deaf children in a number of assessments. The assessments include linguistic, academic and IQ tests. One would expect higher scores on verbal and linguistic assessments to be obtained by those with a post-lingual hearing loss, precisely because these students experienced a period of normal linguistic development. Although the children in the present study all experienced a pre-lingual hearing loss, the issue is raised to highlight the importance of linguistic development on cognitive development.

Braden (1994), for example, in a meta-analysis of studies examining IQ scores, compared deaf subjects who had suffered from hearing impairment at different ages. The verbal IQ scores of deaf students with pre- and post-lingual hearing loss were compared. It was found that the child's age at the onset of hearing impairment had a 'substantial impact' on verbal IQ. Those who suffered a post-lingual hearing loss (here after 5 years of age) had higher verbal scores. Jensema (1975) examined the relationship between academic achievement and the age at onset of hearing loss and found that it had an effect on the vocabulary sub-test of the Stanford achievement test. The students with a post-lingual loss obtained higher scores than those with a pre-lingual loss.

As well as making comparisons on verbal scales and sub-tests, comparisons were also made on academic achievement, non-verbal IQ (Braden, 1994) and mathematics (Jensema, 1975). Braden (1994) found an effect of child's age at onset of hearing loss on scholastic achievement, but not on non-verbal IQ. Jensema (1975) found that those children with a hearing loss after the age of 3 achieved better scores in all the academic areas, with the exception of mathematics computation - the area considered to be least dependent on linguistic skills. It appears that not only does hearing impairment impact on linguistic development, but it could also have a broader consequence on children's development, influencing academic achievement and cognitive development. There are two possibilities as to how hearing impairment may impact on a child's cognitive development. The first suggests that the developmental path hearing impaired children follow is different from that of normally hearing children, demonstrating a *qualitative* difference. The second possibility is that hearing impaired children develop in the same way as hearing children, except that they experience a delay, thereby demonstrating a *quantitative* difference. The following section examines the different theories concerned with the cognitive development of hearing impaired children.

1.3 Cognitive development of hearing impaired children

An understanding of the different theories concerning the cognitive development of hearing impaired children will provide a framework for understanding numeracy development. Conclusions drawn from studies assessing general cognitive skills should be transferable to a specific cognitive ability. Much of the research has compared the performance of hearing and hearing impaired participants on a range of tasks assessing cognitive skills. The principle reason for comparing hearing and hearing impaired participants was to investigate the role of language in cognitive development. It was assumed that the deaf lacked oral skills, consequently they would demonstrate a delay or a difference if cognitive skills required linguistic mediation. The following section describes studies in the field of 'Deaf Cognition', the assumptions that lie behind them and conclusions that have been drawn from them. Throughout, the implications of the different theories and conclusions on the educational career of hearing impaired children are addressed.

Tasks that have been used to assess the cognitive skills of the deaf include intelligence tests such as the Wechsler Intelligence Scale for Children (WISC), tests measuring memory capacity and coding, tasks that assess problem solving, and Piagetian tasks. Moores (1994) identified three different perspectives in the research on the cognitive and intellectual capacities of the hearing impaired. These differences arose initially because different assumptions were made about the impact of hearing impairment on the development of the brain and cognition. Some researchers concluded that hearing impairment would qualitatively alter cognitive development from birth, whereas others disagreed and found no qualitative differences. These assumptions led to the use of contrasting methodologies by the researchers; for example in the tasks presented and the methods of presentation. The different perspectives identified by Moores (1994) can be broadly associated with three consecutive chronological periods. For this reason, the study of deaf cognition will be described from a historical perspective. In addition to the perspectives outlined by Moores (1994) the following section includes the impact of Vygotsky's work on the research concerned with the cognition of hearing impaired children.

Initially, research on deaf cognition focused on differences in scores obtained by the deaf and hearing on intelligence tests scores. Gradually research examined the performance of the deaf in alternative cognitive tasks and the results in these studies began to inform and alter opinions of researchers interested in the cognition of the hearing impaired. Although the research described in the following section has been placed in a separate category of 'Deaf Cognition', it must be stressed that this is not strictly accurate. Contemporary psychological paradigms and theories have fuelled much of the research concerning the cognition of the deaf. Indeed, the hearing impaired have been referred to as the ideal participants on whom to test theories based on studies with hearing participants (e.g. Braden, 1994). Furth (1966) considered the deaf as a group 'without language' and therefore ideal for examining whether cognitive concepts could develop without linguistic ability.

1.3.1 The deaf as quantitatively and qualitatively different

The original studies examining the cognition of deaf individuals compared the performance of the deaf and hearing on intelligence tests. Pintner, one of the first psychologists to examine this area conducted numerous studies. In one study, he and his colleagues, (Pintner and Paterson, 1915a), administered the Binet scale to a sample of 22 deaf students, aged between 8 and 20 years, attending a school for the deaf,. The aim of the study was to establish whether the scale was an appropriate tool for measuring the intellectual ability of deaf students. Of the 22 students in the sample, four were unable to complete the test because of difficulties encountered with the administration (these difficulties were not specified). The average mental age calculated from the scores obtained the particpants was '7.9, or 4.58 years behind' their hearing peers. Pintner and Paterson (1915a) added, '...obviously this does not mean that the normal deaf child is four and one-half years retarded as tested by the scale, but it does seem to suggest the question whether, perhaps the normal deaf child is not on the whole more backward than the hearing child of the same age...(p. 209)'. After concluding that the Binet scale was unsuitable for assessing deaf children, it was suggested that performance scales might be more appropriate. Pintner and Paterson, in the same year (1915b), administered a digit symbol test as a class test to 325 pupils in a school for the deaf. The age range of the pupils was 9 to 'over 18' years. The results of the test were then compared with hearing norms and the comparison showed that 3.4% of the deaf pupils were 'super-normal' (more than one year more advanced than the norms). 23.7 % of the pupils were 'average' (within a year above or below the norm) and 32.6% were 2 to 4 years behind the hearing norm. Lastly, 40.3% of the pupils were more than four years behind the hearing norm. On the basis of this, Pintner and Paterson (1915b) supported the conclusion drawn in their previous study that, in general, the deaf were 'duller' than their hearing peers.

Pintner also attempted to explain why deaf people were cognitively less able than their hearing peers. Pintner (Pintner & Paterson 1915b) linked these differences directly to hearing impairment and its consequence on the development of the brain (and therefore on cognition). Pintner thought that 'disease' was the primary cause of hearing impairment. In addition to causing hearing loss, these diseases were also responsible for damage in the brain and its functioning. This explanation of hearing impairment rendered the cognition of the deaf as qualitatively and quantitatively different from hearing people. Although it is true that some causes of hearing impairment can be associated with neurological damage, this is not always the case. Pintner was criticised on methodological grounds and his conclusions were questioned. In particular, criticisms were made about Pintner's administration of intelligence tests. Pintner administered IQ tests in group sessions, presenting the instructions in a written format with oral and gestured explanations. When comparing hearing impaired participants with norms based on hearing people he made three assumption. The first was that the participants had all understood the instructions equally well, the second, that the deaf and hearing populations were comparable with regards to exposure to the concepts being assessed in the tests. The third and the third that both groups had equal linguistic competence with which to display understanding of these concepts. Pintner (and subsequent research) also found that a large minority of participants were able to attain levels that were comparable to or above the average achieved by hearing populations on which the norms were based. For example, in Pintner and Paterson (1915b), 27.1% of the deaf sample taking the performance task were 'super-normal' or 'average'. Pintner's explanation for the underachievement of the hearing impaired in intelligence tests was unable to account for a number of deaf participants performing as well as hearing participants. Moreover, Myklebust (1964) described a movement, after the studies conducted by Pintner, towards individual testing using performance scales and quoted studies such as Schick (1934), Streng and Kirk (1938), and Myklebust and Burchard (1945) using a variety of assessments. Myklebust reported that, when individual performance tests were used, the general IQ scores of children in schools for the deaf indicated that they were of average intelligence. In summary he concluded that the '...range of the intelligence levels of the hearing impaired does not differ from the hearing ... irrespective of the degree of deafness or of the age of onset...'(p. 63). Alternatives to Pintner's position were required to explain these findings.

1.3.2 Qualitatively, but not quantitatively different

Despite finding that deaf participants were obtaining comparable IQ scores, Myklebust related that educators were becoming concerned because those hearing impaired pupils with average intelligence were still underachieving academically. An alternative position providing new explanations for this discrepancy began to emerge and Myklebust was its main proponent. This view described the cognition of the deaf as qualitatively different but not necessarily quantitatively different. In other words, the hearing impaired could perform as well as the hearing in general assessments, but as a direct consequence of their hearing impairment they accessed information differently - the consequence being to alter the normal path of development from that found in hearing people. Myklebust (1964) reasoned that the development of language was necessary for the development of psychological processes and learning. He summarised his position as follows:

> "A philosophical position commonly held is that without language there is no thought and inferentially there is no intelligence of the type associated with the human being. This implies that if language development is precluded, mental development will be affected. If normal development is necessary for normal development of psychological processes and learning, then the intellectual growth and functioning of the deaf child will not parallel that of the hearing child. On a broader basis, even the preverbal experience of the child deaf from infancy is different from the hearing. His experience does not include audition, hence his non-verbal behaviour, such as perceptual processes, is established and structured differently." (p. 60; Myklebust, 1964)

This opinion of the deaf as qualitatively, but not quantitatively, different emerged as a result of studies examining the performance profiles of the deaf in IQ tests. Myklebust conducted an analysis of previous studies that had used scales with various sub-tests such as the Wechsler-Bellevue test, the Primary Mental abilities test, and studies of memory abilities. Performance profiles of the hearing and deaf participants were compared across sub-tests of the scales. This led Myklebust (1964) to conclude that although a deaf and a hearing subject might obtain the same overall score on an assessment, it did not necessarily mean that the hearing and deaf child had the same abilities on all the sub-tests. An analysis of scales revealed that the deaf and the hearing participants performed differently on different sub-tests. Myklebust interpreted the deaf participants' lower performance on certain sub-tests (including verbal sub-tests) and higher performance on other items, such as the Knox cube and memory for design (both performance tasks), as evidence for '...a basic indication of the influence of deafness on mental development...' (p. 75). In other words, hearing loss had a direct impact on the way the brain developed and consequently on future cognitive development. More specifically, Myklebust concluded that the lower performance on some sub-tests indicated that the hearing impaired were less able than hearing participants to perform tasks that required abstract reasoning. This analysis, and an examination of essays written by hearing impaired students, led Myklebust (1964) to conclude that the impact of hearing impairment was to make the cognition of the deaf 'more concrete' and 'less flexible'.

The theory that deaf people accessed information about the world in different ways to hearing people was not explored directly by Myklebust (1964) but memory tasks support this position. Hermelin and O'Connor (e.g. O'Connor & Hermelin, 1972; Hermemlin & O'Connor, 1973) administered a series of memory tasks that investigated the coding strategies of the deaf. O'Connor and Hermelin (1972) examined the recall ability of deaf, blind and hearing children; all aged 13 to 14 years. (Only the results relevant to the deaf children will be reported here). The children were asked to recall three digits, which were presented either spatially -- following a left to right order (windows 1, 2 and then 3), or temporally -- following a sequential order, one after the other; for example window 2 then window 3 and lastly window 1. The children were asked to identify the 'middle' digit in the presentation. The digits were first shown in a congruent spatial and temporal order. The task was then varied and the spatial and temporal presentations were no longer congruent.

O'Connor and Hermelin (1972) found no quantitative differences in ability to perform the tasks between the groups, but they did identify a qualitative difference in responses. The hearing children consistently responded that the middle digit was the second digit in the order of presentation. The deaf participants, however, reported the middle digit was the one in the middle of the array (window 2) - regardless of the temporal order in which the digit had been shown. This study was replicated with different task designs and the same pattern of recall in the deaf was still found. The deaf showed a tendency to encode information spatially, whereas the hearing children preferred to encode the information temporally (Hermelin & O'Connor, 1973; 1977).

A preference for coding information visually has also been observed in other types of tasks. Fok and Bellugi (1986) investigated Chinese deaf and hearing children who were starting to learn how to write. Chinese script consists of symbols called logographs. The rules for producing logographs are different from the production rules when writing in English, the rules for English being essentially phonetically driven. In Chinese script there are two components, the semantic radical and the phonetic component. The phonetic component is sound-based whereas the semantic radical represents morphemes. Fok and Bellugi (1986) examined the error patterns made by hearing and deaf children. They hypothesised that deaf children would make errors based on the visual arrangement of the logographs, whereas hearing children would make sound-based mistakes. The hypothesis was supported, the hearing children made errors based on phonetic confusions; for example they often wrote the logograph for 'to use' instead of 'already' because they both sound the same (/yi/) but are written differently. The deaf children, on the other hand, made no sound based errors. They tended to substitute structurally similar components confusing characters that looked similar (but did not sound similar or have a similar meaning). The deaf children also made errors by producing 'nonsense' characters that were spatially and configurationally correct (Fok & Bellugi, 1986; p. 333). This indicates that the writing of the deaf children was being driven by rules based on the visual components of Chinese writing. The finding of a qualitative difference in encoding strategies by hearing impaired participants, and the preference for encoding information visually, creates a paradox because according to the theoretical model of short term memory, qualitative differences should to lead to quantitative differences. Myklebust's position states that the hearing impaired will demonstrate qualitative, but no quantitative, differences.

Figure 1.2 summarises the model of short term memory developed as a result of comprehensive research on the abilities and errors made by hearing adults and children when recalling information under a number of different conditions (e.g. Hitch & Baddeley, 1976; Baddeley, Lewis & Vallar, 1984; Hitch, 1984). (Please see

Chalifoux (1990) for a review of the research with hearing subjects upon which the model is based.) Chalifoux (1990) also described the function of each of the components in the model. The 'central executive' acts as the controlling force of the other subsystems of working memory. The central executive allocates attention to the incoming stimuli and is flexible to the modality of that information. The articulatory loop consists of a speech sound-based storage system that is maintained for short periods of time by covert or overt verbal rehearsal. The primary acoustic store forms a temporary sound-based representation of incoming stimuli. The visuo-spatial scratchpad is a system that involves both the visual and spatial processes in the working memory.

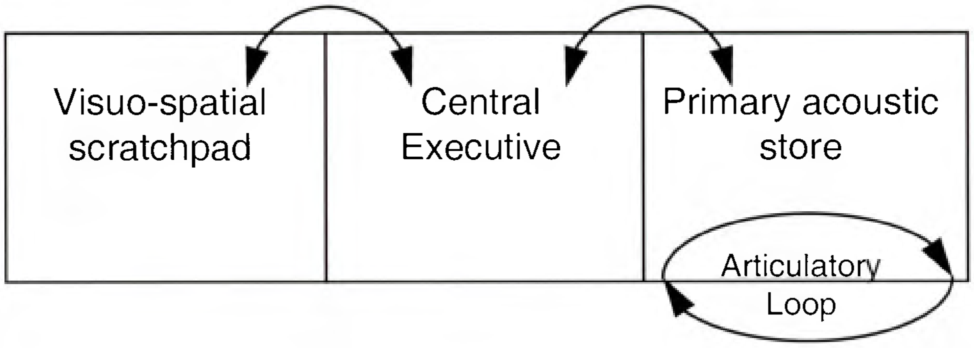


Figure 1. 2. Main components of short-term memory (according to Baddeley)

The components of this model rely heavily on oral and auditory skill, and have implications for the memory abilities of the hearing impaired. Original questions asked whether deaf participants were able to memorise without the use of the acoustic store (or at least with less reliance on the acoustic store) or with a reduced ability to use the articulatory loop. The studies described so far (Hermelin & O'Connor, 1977; Fok & Bellugi, 1986) indicate a preference for coding information visually. However, research has shown that oral skills are not necessarily absent in hearing impaired children. For example, Conrad (1979) and Leybaert (1993) both found evidence of the use of phonological codes and awareness of rhyme in hearing impaired children. This should mean that hearing impaired children should be able to demonstrate the use of phonological or oral coding, even if it is not as efficient as that demonstrated by hearing children. Questions also arose concerning the efficiency (or capacity) of short-term memory in deaf participants. If the articulatory loop is primarily a 'storage system' that depends on verbal skill, then lesser verbal ability (or the choice to encode information differently) should lead to a more fragile storage system. A more fragile storage system would have the consequence of reducing the amount of information that could be stored and remembered. One way of assessing this is to compare deaf and hearing participants on memory capacity tasks. This can be achieved by measuring the memory span of the deaf in comparison to the hearing; i.e. the amount of information that can be retained and recalled correctly. If it is found that the hearing impaired do demonstrate a smaller memory capacity, subsequent questions must ask whether this is as a result of reduced verbal ability and/or a preference for alternative coding strategies.

Blair (1957) presented fifty-three deaf children and fifty-three hearing children with six memory tasks, four of which assessed memory span. These tasks were two digit span tasks (forward recall and backward recall), a picture span and a dot pattern span (using dominoes). The number of items that can be recalled correctly determines the length of a person's span. The other two tasks were Knox cubes test and the memory for designs test. In the Knox cubes test the task was to replicate the order in which the experimenter tapped a set of cubes. In the memory for designs test the children were required to observe cards with geometric figures for two seconds and then draw the design. The deaf children performed better than the hearing children in the Knox cube and memory for design tasks. However, the hearing children performed better in all the memory span tasks, displaying larger memory spans; in other words, the hearing children were able to recall more objects in the correct order than the deaf participants. More recent research comparing hearing impaired and hearing participants on tasks assessing short-term memory span has also found a significantly smaller span in the hearing impaired participants (e.g. Chincotta & Chincotta, 1996).

One method of establishing whether the smaller memory spans are as a result of different coding strategies is to compare performance in a recall task and to compare strategies implemented when encoding and examine the errors made in recall by the hearing and deaf participants. Wallace and Corballis (1973), in two different studies, examined these strategies using verbal material and investigated the confusions made by deaf and hearing participants when recalling visually presented letters. In the first of the two studies three different groups participated: eight hearing 11- to 14-year olds; eight deaf 11- to 14-year olds educated in an oral school; and eight 14- to 27-year olds educated with a manual method that focused particularly on finger-spelling. Both groups of hearing impaired participants had hearing losses greater than 75dB. The participants were required to recall strings of four and five letters in upper and lower cases. It was hypothesised that the hearing would confuse letters that sounded similar, and that because the deaf participants relied on a visual code, the deaf participants would confuse letters that looked similar.

Once age was controlled for, there were significant differences between the hearing and the deaf participants on the mean total number of letters recalled correctly. There were no significant differences between the two hearing impaired groups. The hearing participants performed better than both of the deaf groups. The errors made by the participants revealed the types of strategies and codes being used. The hearing group was assumed to be using an acoustic code because they confused the letters B, E, D, G, and T, regardless of whether they were upper or lower case. The hearing children also showed evidence of visual coding when the letter strings were longer. The errors made by the oral deaf group in the shorter letter strings were primarily confusions of letters that looked alike, indicating a reliance on visual coding. The same participants also confused letters that sounded alike in the longer strings, demonstrating the ability to use an acoustic coding strategy. The manual deaf group made errors with letters that looked alike, such as the letters ‘g’ and ‘q’ (the letters looked as follows: ‘g’ and ‘q’). They made fewer visual errors than the oral deaf group, but this was still their primary source of mistakes. There was also evidence that another code was being used but the authors could not identify the code since there was no confusion between letters that were signed similarly.

The results in the first study by Wallace and Corballis (1973) provide support for the theoretical model of short term memory. The hearing participants performed better in the task and they were relying on an auditory strategy. Another way of testing the model is to compare two groups of hearing impaired participants, an oral and a manually trained group. The model indicates that those with better phonological skills would be in a better position to implement and use the phonological loop for rehearsing information. In this case, an orally trained group should indicate more use of an auditory strategy, and demonstrate a larger memory capacity than a manually trained group. The second study (Wallace & Corballis, 1973) involving a delayed recall task, compared nine oral and nine manual deaf students aged 14 to 19 years who did not take part in the previous study. The students were required to write down letters as they were presented and recall them after a ten-second interval. The two groups differed in the strategies used to rehearse - the manual group made finger-spelling gestures throughout the session whereas all the oral deaf participants moved their mouths and verbalised. The manual deaf participants were significantly better than the oral deaf participants, they recalled more items correctly and confused less items. The most common mistakes made by the participants in both groups were visual. The oral deaf group showed some acoustic confusion but the manual deaf group did not confuse any letters that were signed similarly.

The second study does not support the idea that orally trained deaf participants will perform better than manually trained participants. There may be for a number of reasons for this: firstly the manually trained group were using finger spelling to encode the information and they probably also received speech and language training. This raises doubts about the oral/manual distinction between the two groups; secondly, it may also be that participants in the orally trained group were using an encoding strategy that was not as efficient as the one implemented by the manually trained group because it relied on incomplete oral skills. This suggests that it may be better to encode information in a coding system that is efficient, rather than a system that is specifically oral. It may be that the oral group used visual skills as a second ‘backup’ strategy when the task became too demanding of their oral skills.

The studies by Wallace and Corballis (1973) indicate that both the hearing impaired groups had flexibility in the use of codes, even though the participants used differing communication methods. The first study showed significant differences in task accuracy between the hearing and deaf groups, the hearing participants performed better than the two deaf groups. However there were no significant differences in task accuracy between the two deaf groups. An analysis of strategies used revealed that both deaf groups were relying primarily on a visual code. The hearing participants mostly made confusions with letters that sounded alike suggesting that they were relying primarily on an acoustic code. A detailed analysis of the rehearsal methods in the second study demonstrated that both the deaf groups were able to use a combination of visual and acoustic codes. This study again confirms a preference by the hearing impaired students for visual coding in memory tasks. However, these findings also suggest that a preference does not necessarily imply an inability to use alternative codes, even when accessing oral information. On the contrary, the use of these coding strategies was demonstrated, even though the participants were profoundly deaf. However, the qualitative differences in encoding strategies does appear to lead to differences in quantitative differences in memory capacity.

In the first Wallace and Corballis (1977) study described above, the hearing participants performed significantly better than the hearing impaired participants. One reason for this may be that the stimuli was biased towards phonological coding and therefore favoured the hearing participants. Todman and Seedhouse (1994) compared the recall ability of deaf and hearing children, who were matched on age and non-verbal reasoning ability with visual stimuli. The children were taught to associate visual stimuli with an action and were then tested on a short term memory task that was presented in three different ways. In the first condition the stimuli were presented simultaneously and the order of the recall was 'free', that is, in no particular order. In the second and third conditions the stimuli were presented sequentially. Recall in the second condition was free but in the third it was sequential, following the order of the presentation of stimuli.

The deaf children demonstrated significantly better recall than the hearing children in the 'simultaneous presentation: free recall' condition but showed significantly worse recall in the 'sequential presentation and recall' condition. There were no significant differences in the 'sequential presentation: free recall' condition. Even though all the children were presented with visual stimuli, it seemed that the deaf children were at a disadvantage, in comparison with the hearing children if forced, by task requirements, to recall the information sequentially as well.

Although the children in the Todman and Seedhouse (1994) study were matched for non-verbal reasoning ability, Baddeley's model of working memory suggests that it is phonological ability that should be controlled for. One way of doing this may be to compare the performance of hearing and hearing impaired participants with similar levels of phonological or linguistic skills. One study that made such a comparison was carried out by MacSweeney, Campbell and Donlan (1996) who examined the short-term memory coding in British deaf 15-year olds and compared them with different groups of hearing participants. One of the hearing groups was the same age as the hearing impaired participants, the other group of hearing participants were children with the same reading age as the deaf participants. It can be assumed, though this was not stated specifically in the study, that the participants matched on reading age will possess similar levels of phonological skill, whether hearing or hearing impaired. MacSweeney *et al.* (1996) also matched these three groups on memory capacity, they all correctly recalled at least 50% of the items of a list of drawings with no similarities. MacSweeney *et al.* (1996) examined the codes used by hearing impaired teenagers and asked whether they were as 'secure' as those implemented by hearing children. The participants all took part in two studies where they were shown and asked to recall lists of drawings. The first study examined the effects of articulatory-, motor- and sign-suppression on ability to recall listed items. The second study examined the ability to recall lists of drawings that differed in content. In both studies the deaf were compared with hearing participants matched for memory capacity and chronological and reading ages.

The first study was based upon the paradigm that it is possible to identify how the participants encode information by introducing different types of interference. For example, interference in verbal encoding can be introduced repeatedly saying a word - 'articulatory' suppression - and would prevent the effective use of a verbal code to encode information. If a verbal code were being used, this would have the consequence of lowering the number of items recalled correctly. Examination and comparison of different types of suppression on recall of drawings revealed that the groups recalled a comparable mean numbers of items correctly in the condition with no interference - the 'control' condition with no suppression. When different types of interference were introduced, it was found that all the groups were affected by articulatory suppression. Less numbers of items were recalled correctly, indicating the use of a verbal code to encode. However, both hearing groups were significantly more affected than the deaf group, indicating that the hearing groups were making more mistakes and relying on verbal encoding more than the deaf group. In the other task conditions, the deaf group resembled their reading age matched peers more than the older hearing participants in the study. Concurrent hand movement, motor suppression, influenced recall in the young hearing group and the deaf group more than in the older hearing group. Sign suppression only had an impact on the participants in the deaf group. From these findings, MacSweeney *et al.* (1996) concluded that the deaf participants were using both speech- and sign-based codes.

The second study examined the impact of lists of different pictures on memory span. There were four different conditions. The first condition contained a list of pictures that had no similarities and this was the ‘control’ condition. The other three conditions consisted of lists of pictures with similar items. One contained items that were phonologically similar, another contained items that were visually similar, the last list consisted of items that were formationally similar - these were items that had similar signs. In this study there were four groups of participants, deaf teenagers, hearing 11-year olds, hearing reading-age matched children (around 8 years old), and hearing 5-year old children.

The hearing 11-year olds made more errors in the phonologically similar condition, suggesting use of a speech code. The hearing 5-year olds committed more mistakes in the visually similar list of drawings, indicating a use of a visual code. The deaf participants and the reading-age matched hearing children made the most errors in the visually and phonologically similar conditions. Recall of the list of formationally similar drawings only reached borderline significance for the deaf group. Again, the second study found that the deaf teenagers’ performance resembled the reading-age matched hearing children, who were using a combination of speech and visual codes. However, the fact that the participants were all matched for memory capacity suggests that these differences in coding preferences do not impair the memory capacity of hearing impaired participants. There were also a group of hearing impaired participants, who were approached but could not take part in the study because they did not reach the criterion level of a 50% pass rate in the control task. It could be that these children have different encoding strategies that are detrimental to memory coding ability. Despite the fact that different research methods have been used to investigate the memory capacities of the hearing impaired, the studies show similar findings, that the hearing impaired demonstrate the use of a variety of coding strategies, visual and verbal. It appears that the manipulation of the stimuli from verbal to more visual has some impact on the amount of information that can be recalled by the hearing impaired participants. However, the role of the phonological loop and alternative coding strategies has to be investigated further, perhaps by comparing hearing impaired participants with a range phonological abilities with a variety of types of stimuli.

Despite finding different coding preferences, support for the position promoted by Myklebust (1964) has waned because of extensive re-examination of the performance of hearing impaired and hearing participants taking IQ tests. Braden (1984, 1992, 1994) carried out work with deaf participants and their performance in IQ tests. The first of these studies (Braden, 1984) examined the factorial similarity of the WISC-R performance scale in deaf and hearing samples. Braden (1984) re-examined and compared the data from two previous studies; the first, with hearing impaired participants, from a study by Anderson and Sisco (1977) and the second, with hearing participants, from a study by Wechsler (1974). Braden (1984) found that the metrics and the sub-test factor loading were 'practically identical' for both the hearing and deaf samples. Small mean differences, where the deaf sample performed less well, were attributed to the higher incidence of brain damage among deaf participants.

Braden (1994), in an extensive meta-analysis of studies that examined intelligence scores of the deaf, also found that the average reported IQ scores were significantly correlated to the year of dissemination. In other words, the more recent the study, the higher the reported IQ. Two explanations were put forward for this finding. In the first, the hearing impaired population were 'catching-up' with the hearing in terms of intelligence, i.e. they were becoming more intelligent, or at least more able to perform this type of task. The second explanation was that the original studies underestimated the abilities of the deaf. Braden (1992) categorised all the studies included in the meta-analysis in terms of 'quality'. Those studies rated as 'high' were those deemed to have used appropriate tests and administration methods. Factors taken into account were the type of test (verbal as opposed to non-verbal or performance scales) and the communication mode used for the administration of the test (signed methods as opposed to written or oral). Braden (1992) found that the 'quality' of the test was 'substantially' related to the year of dissemination. Moreover, when the effect of 'quality' was statistically removed from the correlation between the year of dissemination and IQ, there was no relationship between year and IQ. The idea that the earlier studies underestimated the ability of hearing impaired people is supported by Braden's findings. This also suggests that with the appropriate methods the hearing impaired can be assessed adequately.

It is now generally accepted that, as a population, the hearing impaired are no less intelligent or less able to perform intelligence tests than the hearing population if administration procedures for assessments are adequate. The implication is that those hearing impaired children performing at average to above average levels in intelligence tests should be able to perform to comparable levels in academic assessments, including mathematics. However, the concern voiced by Myklebust (1964) regarding the academic under-achievement of those hearing impaired children with average levels of intelligence still holds true today.

1.3.3 Experiential Deficit

As mentioned previously, Myklebust (1964) proposed the theory that cognitive development of the hearing impaired would alter from birth as a direct consequence of sensory deficit caused by their impairment. Piaget's work (e.g. Piaget & Inhelder, 1969; Piaget, 1983) and his theory of cognitive development offered an alternative position and additionally introduced a methodology that could examine the processes of children's thinking and not just the 'end product' of a score such as IQ. Piaget based his work on two assumptions that differed from contemporary opinion. One assumption concerned the relationship between language and thought, the other was concerned with the development of cognitive development during the early childhood years.

In Piaget's theory of cognitive development, a child's perception and way of thinking is qualitatively different to that of an adult. Piaget proposed that particular aspects of cognition dominate at differing times of childhood, and that changes in cognition correspond roughly to different ages. In this theory, cognition develops from being dependent on direct manipulation of concrete objects to becoming more abstract and flexible. Cognitive development commences at birth, not through language or sound, but through interaction with the surrounding environment. This interaction is derived and based on touching and acting upon surrounding objects to develop 'action schemas'. Piaget called this type of thinking 'sensori-motor' cognition. 'Pre-operational' thinking then begins to develop, the child starts solving problems but has particular difficulty in being able to 'decentre' - that is the child only focuses on his or her own perspective and is unable to take other perspectives into account. A child will often come to incorrect conclusions about a situation because he or she concentrates on what can be perceived immediately. Piaget designed a variety of tasks that explore pre-operational thought, for example the range of 'conservation' tasks. In one of these, the conservation of liquid task, water in a glass is transferred to a differently shaped container. According to Piaget, the 'pre-operational' thinker will not realise that the same amount of water is present in the differently shaped glass after the transformation. The child is unable to distance him- or herself from what he or she can see. In a situation where water has been poured from a tall, thin glass to a shorter, wider glass. The 'pre-operational' thinker may, for example, say that there is less water after the transformation because the water in the new glass appears shorter. Children do eventually learn to 'decentre' and manage to solve tasks that require flexibility in thought and consideration of alternative perspectives. Piaget explained that the child's 'flexibility' in thought results from the development of 'operations', these are 'mental representations of actions that obey logical rules' (Berk, 1997). With the acquisition of operations, the child is able to reverse actions and understand rules. Initially these operations are only applied in situations where the objects are present and can be manipulated. The concrete-operational thinker will be able to solve a task such as the conservation of liquid task, but only if the child has had an opportunity to manipulate the objects; for example if the child has had experience of pouring water into different shaped glasses. Eventually, the child will be able to reason that an amount of water remains constant regardless of the shape of the container it is poured into. The concrete-operational thinker, would not however, be able to solve a similar problem in the abstract. Eventually, the ability to solve abstract problems emerges in the child with the development of 'hypothetico-deductive' reasoning. This type of reasoning does not rely on the presence of objects. It allows the thinker to formulate and test hypotheses.

During the end of 'sensori-motor' cognition and the beginning of 'pre-operational' cognition, linguistic ability becomes evident. Piaget also held a differing assumption to his contemporaries such as Myklebust about the role of language in cognition. Piaget proposed that if the general function of language was to express thoughts and concepts, then the concepts must develop before they can be expressed. Eventually language could serve as a mediator for thought, but cognitive development has to begin before language can start to develop.

Piaget's two assumptions, the role of language in cognition and the path of cognitive development, had consequences for the cognitive potential of hearing impaired people. Because cognition was initially dependent on interaction with the environment rather than linguistic ability, or the ability to hear, it was suggested that hearing impaired children could develop along the same paths as hearing children. In Piaget's theory, the development of cognition was thought to be in a fixed order, but the age at which the child arrives at any point of development was not fixed. This introduced the possibility of cognitive development in deaf children being delayed as opposed to different. It also introduced the possibility that hearing impaired children could be as able as hearing children with tasks that required reasoning, but with no (or little) reliance on language. Piaget also developed a methodology for investigating children's thinking. Tasks, such as the conservation of liquid task, required children to solve problems and then talk about their solutions. These tasks were eventually termed as 'Piagetian' or Piagetian-type' tasks. A number of psychologists presented Piagetian tasks to the deaf (e.g. Furth, 1966; Oléron, 1977) with the purpose of 'testing' Piaget's theory on a group of people who were classified as being ‘without’ language. An additional aim was to assess the nature of deaf people’s reasoning and cognition, as opposed to the levels of intelligence in previous tests administered by Pintner (e.g. Pintner & Paterson, 1915a). Piagetian-type tasks adapted for use with hearing impaired children were presented in a number of studies. If deaf children were able to solve such Piagetian-types tasks, this would then provide support for the theory that intellect can develop without language (Furth, 1966). The results of these studies were conflicting. In some the deaf performed as well as hearing participants, in others they did not.

Furth, (1964, cited in Furth, 1966) gave a series of sorting tasks to 30 deaf adults and compared their success with 30 hearing adults. Furth taught the participants of the study how to categorise cards into two boxes according to a specific criterion. The criteria on the tasks varied. For example, with some items, the criterion was colour (‘colour same’ versus ‘colour different’). With other items the criterion was form (‘same’ versus ‘different’). On another occasion task the criterion was to sort the cards according to direction of lines (sorting cards with lines that were vertical or slanted left together but separately from cards with lines that were horizontal or slanting to the right). When the performance of the hearing impaired was compared with that of normally hearing participants, Furth found that with some tasks (sorting by colour and form), the two groups performed as well as each other. However there were differences in success rate when the task required the use of the ‘lines’ criteria. In these cases the hearing impaired participants performed less well than the normally hearing participants did.

Oléron (1951) also gave hearing impaired adolescents a series of sorting tasks. In Oléron’s task the participants had to successively categorise the same cards a number of times, each time according to a different criterion. For example, cards with a varying number of different coloured shapes could be sorted by colour the first time and then again by shape and then lastly by the number of shapes on the cards. Oléron (1951, cited in Oléron, 1977) found that the hearing impaired participants had no difficulty organising the cards using the first sorting criterion. The same participants, however, found it difficult to shift from the first sorting principle to the next and had a tendency to use the same type of categories again. The inability to shift principle was interpreted as giving the 'impression of rigidity'. The hearing impaired participants also had difficulty in explaining what type of categorisation strategy they had implemented. Oléron hypothesised that the deaf had difficulties in treating the objects to be sorted as members of categories, and this led to the response pattern observed. Oléron stated that abstract and conceptual categories such as colour and number, could present more problems for the hearing impaired than categories based on more concrete concepts. However, Oléron said that difficulties with abstract concepts was indicative of a 'retarded development' rather than a 'real incapacity', and one where the presentation of language and abstract terms could help develop abstract thinking. Furth (1966) gave two possible explanations for the differences of success rate between the hearing and deaf in his study. In one he said the deaf performed worse because the deaf lacked experience with the type of stimuli presented in his study. The other explanation focused on the sign of 'slant' that is made regardless of the direction of the line. Ambiguities about this sign could have made it difficult for the participants to 'discover the breakdown of the category "slanted" into "slanted left" or "slanted right"'(Furth, 1966 p. 135).

Other tasks presented to hearing impaired participants also seem to demonstrate conflicting results. Administration of seriation tasks (e.g. Borelli, 1951) found no differences between the hearing and deaf participants. Studies examining conservation (Oléron & Herren, 1961; Furth, 1964; 1966) demonstrated a difference in performance between the hearing and deaf participants. These results were replicated more recently by other studies (Rittenhouse & Spiro, 1979; Watts 1982). A better performance was demonstrated by the hearing groups than the deaf groups of participants in the whole range of conservation tasks (weight, area, number, quantity and length).

Ottem (1980) reviewed 51 studies that assessed the cognitive abilities of hearing impaired participants. The studies described above by Furth (1964) and Oléron (1951) were also included in the review. The studies were re-categorised into the types of tasks the participants were asked to perform: discrimination; association; memory; rule learning; 'Piaget-type' tasks; sorting classification and practical problems. Ottem (1980) also made an additional distinction within this classification and identified those tasks that required the participants to examine problems with one variable, and those tasks that required the participants to reason about two variables. In the 'one-variable' problems the deaf people performed equally as well as hearing people. However, when the performance of deaf and hearing participants was compared on 'two-variable' tasks, the deaf performed significantly worse than the hearing participants did. The 'lines' task administered by Furth (1964), for example, was classified as a 'two-variable' problem because it required participants to group two sets of lines together (slanted left and vertical) while simultaneously distinguishing them from another two sets of lines (slanted right and horizontal). Ottem (1980), in an attempt to explain the difference of success between the hearing and hearing impaired, suggested that the hearing impaired '...have been particularly trained or taught to communicate about single events...' (Ottem 1980, p. 568). This implies that the lower performance demonstrated by the hearing impaired children is as a result of inexperience with problem solving situations, and that the cognitive potential of hearing impaired students is not being fulfilled.

Other features of cognitive behaviour have also been examined in the hearing impaired. One aspect that has been noted and investigated is the behaviour of hearing impaired children when engaged in problem solving activities. An informal observation noted in the literature is that the deaf do not persevere when problem solving (Das & Ojile, 1995; Luckner & McNeill, 1994). However, this seems at odds with data showing no major qualitative differences in cognitive functioning in comparison with their hearing peers (Braden, 1984). Das and Ojile (1995) examined the performance of students with and without hearing loss in tasks measuring three cognitive processes: planning, simultaneous and successive processing. There were four groups of participants in the study: 'young' deaf and hearing children aged from 9- to 10-years and older deaf and hearing participants aged from 12- to 15-years. The participants were required to take part in six activities (three 'verbal' and three 'non-verbal'). One planning task, for example, was similar to the game 'Mastermind' called 'cracking a code'. For each task item the experimenter laid out a hidden, predetermined sequence of different coloured chips. The children were asked to identify the sequence. In each item there were a number of trials where the child placed a number of chips, the experimenter said how many chips were in the correct position. This was followed by the next trial until the child successfully identified the hidden sequence. Eight items were presented in an increasing order of difficulty. An example of another non-verbal activity was to identify a shape embedded in a more complicated geometric design. One of the verbal tasks was to repeat a list of words (presented orally or in sign). The study yielded qualitative and quantitative data. The children's achievement was scored in each of the six tasks and they were also observed.

Quantitative analysis revealed that, in planning activities, the hearing children were significantly better than the deaf children. The hearing children, younger and older, were quicker at completing the tasks. In the simultaneous and successive processing tasks there were significant differences between hearing and deaf children on the verbal tasks, but not the non-verbal tasks. Qualitative comparisons of strategies implemented were also made in the planning activities. The hearing impaired children were observed to be reliant on the examiners' approval and to require external feedback by asking questions such as 'I finish before time, right?' None of the hearing children demonstrated this type of behaviour. The hearing impaired children also seemed doubtful of their judgements and were sometimes distracted and worried about the attractiveness of their answer, for example in the 'crack the code' task they appeared more concerned that the coloured pegs were arranged to make a pretty pattern.

Luckner and McNeill (1994) also noted that educators and psychologists often express concern about deaf children's ability to solve problems. They compared hearing impaired and hearing participants' ability on a series of problem-solving tasks. Luckner and McNeill (1994) examined the existence and extent of differences in problem solving ability between the hearing impaired and hearing participants. As well as noting differences across age groups they examined whether there was evidence of an improvement in problem solving ability. Any rates of improvement shown by the participants were also compared. Deaf children aged between 6- to 19-years and hearing children (matched on age, gender and 'race') were asked to complete a Tower of Hanoi problem. This problem consisted of a number of discs placed on three vertical pegs. The discs were graduated in size and were placed on one of the pegs with the largest disc at the bottom and the smallest at the top. The aim was to move the pyramid of discs to one of the empty pegs by moving one disk at a time and never placing a larger disk on top of a smaller disk. The number of moves the participants made while solving the problem was noted. Comparisons were made between the hearing impaired and the hearing participants, as well as between the groups of different aged participants, (5-8, 9-10, 11-12, 13+ years). Luckner and McNeill (1994) found that the hearing children performed better than the deaf children and managed to obtain the solution in fewer moves. The older children (deaf and hearing) solved the problem more quickly than the younger children, again solving it in fewer moves. There was no interaction between hearing status and age. This suggests that the hearing impaired groups improved at the same rate as the hearing children. Again the study supports the view that hearing impaired children do demonstrate a delay in cognitive skills in comparison with hearing children.

The two studies described above confirm the concerns voiced by educators and psychologists. Generally, the deaf take longer to solve problems and sometimes display a reliance on immature strategies such as depending on external feedback from teachers. Luckner and McNeill (1994) suggested that poor language skill might inhibit abstract reasoning ability, which may explain this delay. It was also suggested that the hearing impaired have poor problem solving skills because they lack experience of situations where these skills are necessary. These researchers support the suggestion that the cognitive potential of hearing impaired children was not being fulfilled as a consequence of ‘experiential deficit’, the lack of exposure to experiences and incidental knowledge that hearing children acquire on a daily, informal basis.

1.3.4 Communication requirements

The work by the Russian psychologist Vygotsky has had a major impact on research in general child development. Although he worked in the Soviet Union from 1920 to 1940, it is only relatively recently that his work (after translation in the 1960s) has become accessible to Western psychologists. Vygotsky’s work has made two major contributions (e.g. Vygotsky, 1962). The first concerns the relationship between thought and language, and more specifically, the role of language in cognitive development. The other contribution is related to the role of social interaction in learning. A comprehensive description of Vygotsky's theory and research is beyond the scope of this thesis, but the role of social interaction in learning will be covered briefly because Vygotsky considered it to be important for the child's cognitive development. The child acquires knowledge of cultural conventions and tools for thinking - for example a script or a counting system, through interaction with others, usually adults. Once the child has acquired these tools, they are then internalised and used to structure further thinking. The internalisation of cultural tools enables more abstract or, as Vygotsky termed it, 'higher order' thinking. Important in this interaction is the role of 'intersubjectivity' - the shared understanding between the child and the adult. Without intersubjectivity, the child-adult dyad cannot share problem situations or collaborate to solve them. Additionally, the child is also unable to acquire, and internalise, tools for solving problems. Rogoff (1990) describes the adult's role in a dyad-interaction with a child as one that initially structures the activity and provides guidance on how to solve the problem within the child's abilities. Guidance is considered effective if the adult successfully transfers the responsibility for structuring the activity from themselves to the child.

Recently, the relevance of Vygotsky's ideas for the cognitive development of the hearing impaired has been considered. Researchers examined, for example, the interaction between a deaf child and his or her mother (e.g. Jamieson, 1994) and whether a bilingual/bicultural approach to deaf education would be appropriate (e.g. Hayes, Dilka & Olson, 1991). Vygotsky also wrote about the development of hearing impaired children - some of this work has only recently been translated (e.g. Vygotsky, 1993; van der Veer & Valsiner, 1994). Vygotsky (1993) proposed that there were two paths of development, the 'natural', and the 'cultural'. The 'natural' path is concerned with biological aspects such as maturation; the 'cultural' path involves the acquisition of cultural tools. Whereas in the normally developing child these two paths are difficult to separate, Vygotsky saw that this was not the case in hearing impaired children. Although the origin of the impairment is biological, developmental difficulties will occur along the cultural path. Hearing impairment,

'... not only alters the child's relationship with the world, but above all affects his or her interaction with other people...' (Vygotsky, 1993; p.111). The deaf child's biological development is not necessarily affected by his or her hearing impairment; deaf children mature at the same rate as hearing children, which implies that the potential for learning in a deaf child is the same as that of the hearing child. For Vygotsky, the consequence of impeded cultural development would be to arrest the deaf child's development at a 'primitive' cognitive level; that is, at a level where he or she is unable to use cultural tools to facilitate abstract (or higher order) thinking. As mentioned previously, in the normally developing child, the acquisition of cultural tools occurs through interaction with others; this should be the same process for the impaired child, hearing or deaf. Vygotsky proposed that 'primitivism' can be combated by communicating through specially created cultural 'forms', such as Braille for blind children and 'the gesticulated, mimed speech of the deaf-mute (p. 43)' for hearing impaired children. Even though these specially created forms may require different psychological processes - for instance, reading script is accessed through vision and reading Braille through touch - Vygotsky proposed that they fulfilled the same cultural function; the transmission of information. The challenge in education would then be to create paths of communication with the hearing impaired child so that cultural tools can be transmitted to them. In this way the tools can be internalised so that the child can achieve abstract thought.

Vygotskian theory places much emphasis on the role of interaction for learning. A child who encounters difficulties in these interactions would be at risk for falling behind in learning. The hearing impaired child may not acquire a particular cultural tool and may not have access to as much information as a normally hearing child. Researchers have examined interactions with deaf children and asked whether deaf children are at risk during these interactions. Shaw and Jamieson (1995), for example, observed the interactions of a deaf child attending a mainstream school. Jamieson (1994; 1998) compared the interactions of deaf and hearing mothers with deaf children working together to solve a task.

Studies observing interactions have found that communication with deaf children is particularly prone to breakdown. Shaw and Jamieson (1995) videotaped a deaf boy for nine hours in both social and instructional settings in a mainstream school. The boy was the only deaf child in the school. The study examined the frequency and amount of interaction with hearing partners, the kinds of interactions, the means of communication, the use of eye contact, and the repair and avoidance of communication breakdown. For a large portion of the observation sessions outside the classroom, the child spent his time playing alone. When interactions did occur with classmates they were often 'single bout' interactions such as 'question-answer' or 'comment-response'. The most common methods of mediation, in and outside the classroom, between the children were non-linguistic, such as pointing, gestures and mime. Occasionally single Signs were used with those children who knew some Sign. The child's longest and most frequent interactions were generally in the classroom with the interpreter.

Shaw and Jamieson (1995) observed many incidences of communication breakdown. Only the child's interpreter appeared to have strategies for successfully repairing these breakdowns. The child would repeat Signs more clearly or add voice to his sign but this did not always work because his speaking voice was unclear. The hearing children used physical directives or asked the interpreter to intervene. Shaw and Jamieson (1995) discussed success in achieving intersubjectivity in the observed interactions. It was found that intersubjectivity between children was limited to interactions that revolved around present objects or events. The topic had to be highly contextualised in order for both parties to share the same understanding from the interaction.

Jamieson (1994) compared the interactions of different mother-child dyads when completing a task. Three dyads (hearing mother–deaf child; hearing mother–hearing child; and deaf mother–deaf child) were videotaped. Analyses focused on a variety of behaviours within the dyads such as attention getting, direction of gaze, and delivery of message (the mode of communication and use of gestures). Similarities between the hearing mother-hearing child and deaf mother-deaf child became apparent in their abilities to achieve intersubjectivity and guide the child towards self-regulation in the task. These similarities occurred despite the differences in behaviours to establish this interaction; deaf mothers gained and kept the child's attention via the visual channel, whereas hearing mothers used the auditory and visual channels simultaneously. The mothers in both the dyads gave direct instructions during the first minute of interaction and then reduced the amount of support half way through the interaction. Towards the end of the observation session the children initiated the interactions and the mothers monitored the activity by watching.

Differences in the mother's behaviour were observed in the hearing mothers-deaf child dyads. Initially, their behaviour seemed to be similar to that of the other mothers and characterised by instruction, and if the child failed to understand the instructions, the mother repeated them. However, the hearing mothers of deaf children persevered longer than the other mothers in their repetitions of the instructions leaving the child less room for his or her own initiative. The amount of child initiated behaviour did not increase throughout the session, unlike in the other dyads. It appeared that the deaf child was at risk of not achieving intersubjectivity if the communication patterns were not appropriate for the child. The deaf mothers showed an awareness of how to attract the deaf child's attention and how to describe the task to them. The hearing mothers did not demonstrate this skill during the observation sessions.

Wood (1987) also identified achieving intersubjectivity as particularly difficult when interacting with deaf children. Communication relies on a visual mode for deaf children more than for hearing children. A particular difficulty can arise if an adult and child are working a problem together and the adult is saying something about an object. The deaf child has to look at the object being talked about and at the adult to establish what is being said. The child cannot look at both simultaneously. Although Wood (1987) noted these difficulties, he stressed that intersubjectivity can be achieved, however, more attention needs to be paid to the communication process with the deaf child. This was shown in the Jamieson (1994) study. For example, when the child was working on the blocks on the task, deaf mothers gave additional instructions by moving their signing from their body nearer to the child so that the Signs could be seen by the child in their peripheral vision. These studies appear to support the idea that communication can be problematic with deaf children, but that this can be overcome.

1.3.5 Summary

The previous section presented an overview of different viewpoints concerning the cognition of the hearing impaired. The hearing impaired student attains academic levels that are below those of their hearing peers. There could be a variety of explanations for this delay according to the theoretical positions described above. The first viewpoint proposed that cognition of the hearing impaired was quantitatively and qualitatively different. Owing to these differences, the deaf would score less well on intelligence and academic assessments. Because these differences were assumed to be biologically determined, it was also implied that any differences could not be alleviated through education. Pintner did find that the deaf were able to perform well on activities that involved motor and mechanical ability, and that the deaf relied on concrete intelligence. He therefore concluded that the education of the hearing impaired should concentrate on these specific types of tasks. The implicit suggestion is that hearing impaired students will not achieve much academically, except with these tasks which rely on abilities unaffected by their hearing impairment. In other words that hearing impairment is viewed as a cause of the lower attainment levels obtained by this group of students.

The second position described the cognitive abilities of the deaf as qualitatively, but not necessarily quantitatively different. The differences were thought to have biological, and thus causal, roots. Myklebust suggested that, given that 'deafness affects specific mental operations more than others...' (1964; p.104), the curriculum should focus on tasks that give the hearing impaired child training in ' ...various activities ... which could give him practice and training on those aspects of intelligence which seem to be most vulnerable to deafness' (1964; p. 104). Having proposed this, Myklebust (1964) then acknowledged that it was unknown whether these activities would be successful when included in the curriculum for hearing impaired pupils. Research would have to be carried out to examine whether the effects of sensory deprivation could be alleviated through education. Again, no optimistic predictions could be made about the academic or mathematical attainment of hearing impaired children.

The third approach presented considers that hearing impaired children display quantitative differences in comparison with their hearing peers. This underachievement of the hearing impaired could be explained by their experiential circumstances. Because of the linguistic difficulties they experience, they have less exposure to many concepts acquired incidentally by hearing children. The curriculum of the hearing impaired has also been criticised for being too rigid and formal, and for not giving the pupils access to a variety of modes of reasoning. However, this approach also implies that there should be no reasons, if given appropriate time and resources, for not achieving the same academic standards as their hearing peers. This has led to a number of studies investigating the influence of programmes designed to 'enhance' the cognitive potential of deaf individuals (e.g. Martin, 1993). These studies have examined whether teaching programmes, designed originally for hearing children, are also appropriate for teaching hearing impaired children. Results of such intervention studies include adaptations of the LOGO computer programme for deaf students (e.g. Dietz, 1985; Luft, 1985). LOGO is a computer based language used in the mathematics classroom to provide '... opportunities for mathematical investigation, encouraging discussion and project work...' (p. 2; Hoyles & Sutherland, 1992). The preliminary studies with hearing impaired children indicate an increased persistence when dealing with problem solving situations. Dietz (1985) saw evidence of improved and extended planning behaviours. Another programme that has been adapted for use is 'Instrumental Enrichment'. Feuerstein originally developed the programme for culturally disadvantaged groups emigrating to Israel in the 1950s as a formal instruction programme to repair identified deficits in cognitive functioning. The programme consists of more than 500 pages of pencil and paper exercises, divided into 15 instruments. Each instrument focuses on a specific cognitive deficiency (for a complete description see Feuerstein, 1980). Martin (1983) applied a programme of Instrumental Enrichment to a group of deaf adolescents at the Model Secondary school for the Deaf at Gallaudet University. Although only a pilot study, Martin (1993) reported that the students improved 'measurably' in skills of reading comprehension, mathematical computation, systematic approach to problem-solving, organisation of solutions to subject-matter problems, and abstract thinking. Here the predictions for the mathematics learning of hearing impaired children differ from previous research, these studies indicate that the educational standards of the hearing impaired can be improved with alternative methods of teaching. The finding that deaf children can obtain improved academic results supports the idea that hearing impaired children are at risk of under achieving academically. This underachievement can be addressed with more appropriate teaching methods. The risk factor is in this case has been identified as the 'experiential deficit'. One difficulty with identifying 'experience' as a risk factor is that this covers a broad area and it is difficult to remedy in the limited hours of schooling. The issues raised by the Vygotskian research raises an alternative source of risk in learning for hearing impaired children, that of communication. If intersubjectivity between the hearing impaired child and the teacher is achieved, and the child acquires the appropriate cultural tools to become independent mathematical thinkers, they will achieve abstract mathematical thought. Success in obtaining intersubjectivity and creating adequate platforms for communication about mathematics with the deaf child will allow them to become numerate.

The last two positions described above also offer predictions for the numeracy development of children. Nunes (1996) offers an integrated perspective of the different theories of numeracy development. Although the theories relate particularly to hearing children they may also relate to hearing impaired children, given that Nunes (1996) concentrated on the Piagetian and Vygotskian perspectives. Nunes (1996) argues that the two positions offer predictions about the path of acquisition of mathematical concepts. They are summarised briefly below.

Nunes states that the central idea in Piaget's work is that the 'basic meanings of mathematical concepts stem from children's schemas of action - that is generalisable and structured actions, which can be applied to a variety of objects and which centre on the relations between the objects and transformations rather than on the objects *per se*.' In other words, children can compare objects, put things in order, join and separate objects, count in several ways in order to solve problems and make correspondences. According to this perspective, these action schemas will provide the first meanings for mathematical signs that are later taught in school. Because these initial understandings are based on action, there should be no reason for hearing impaired children to demonstrate a delay or lack of understanding in situations where they can implement these action schemas.

In addition to understanding relationships between numbers, children also have to learn socially constructed conventions such as the counting string mathematical signs. In the case of the mathematical signs, continues Nunes (1996), the mathematical signs may not map directly on to the representations developed from action schemas. Here the ideas described by Vygotsky of the transmission of the cultural tools become relevant for the numerical development. Children learn these new mathematical meanings from a more experienced person, such as the school teacher in the classroom. The transition from reasoning based on action schemas to the acquisition of mathematics as a culturally transmitted tool for thought depends on effective communication. This is an area where difficulties arise for hearing impaired children, and for this reason it is thought that they may experience delays in numeracy development.

The following chapter reviews research specific to the mathematics performance of the hearing impaired child and issues related to their numerical development. According to the integrated view of mathematics learning, it is expected that hearing impaired children will demonstrate understanding of mathematical concepts when using action schemas to reason. However some of these children may be delayed in acquiring the cultural mathematical conventions such as counting and the acquisition of mathematical signs. Not all of these children are expected to experience a delay because the research investigating the communication patterns with hearing impaired children show that intersubjectivity can be achieved (Jamieson, 1994), therefore the transmission of cultural tools will be possible for some of these children.

2. Hearing impaired children's achievements in mathematics

2.1 Organisation of the chapter

The following section reviews research comparing the mathematical attainment of hearing impaired students with hearing students. Previous research that attempted to provide explanations for this low attainment is then presented. This research has yielded few explanations for the lower performance levels of the hearing impaired. It is suggested that this may be because a causal relationship between hearing impairment and mathematical attainment has been assumed. It is then argued that an alternative framework for examining the relationship between hearing impairment and mathematical achievement is required. Drawing on the research about the development of numerical concepts in normally hearing children, it is suggested that it may be more accurate to consider hearing impairment as a 'risk factor' rather than a cause. The development of numerical concepts in hearing children is described and, wherever possible, potential difficulties in the numerical development of hearing impaired children are identified using relevant research. Following this, the design and framework of the main studies are described.

2.2 Levels of mathematical performance

Levels of attainment of the hearing impaired have been examined in a number of ways. Firstly, direct comparisons have been made with hearing children by examining the average scores obtained by both groups administered the same tests. Secondly, the distribution of the mathematics scores obtained by the hearing impaired children have also been analysed in an attempt to establish how the hearing impaired population perform as a whole. Lastly, scores obtained in the same assessments administered at two different times have also been compared and examined. This is to establish whether levels of achievement have improved over time in hearing impaired populations.

2.2.1 Comparisons with hearing children

A number of studies carried out in a number of countries since the 1970s, comparing the performance and attainment of hearing impaired children to those of hearing children, show that deaf children perform at an average level that is consistently below that of their hearing peers. For example, Hine (1970) examined the mathematical performance of 104 deaf students, aged 7.8 to 16.5 years, attending a special school for the deaf. The children were administered mathematical tasks that were standardised on a hearing population and provided a standardised score of 'arithmetical ages'. In this way it was possible to compare the performance of the hearing impaired children to the 'average' hearing child by comparing arithmetical age to the chronological age. It was found that the average attainment of a deaf 10-year old was equivalent to that of a hearing 8-year old. A deaf 15-year old was found to have the performance comparable to a hearing 10-year old in mechanical problems and a hearing 11-year old in problem solving arithmetic. However, these results only reflected the attainment of students attending one school, and the author acknowledged the restrictions generalising about the hearing impaired school population as whole on the basis of data from one school.

However, Wood *et al.* (1986) obtained similar findings when they examined mathematical reasoning and numeracy of a group of deaf school-leavers from schools around England and Wales. One thousand pupils, half of whom were deaf, were given the Graded Arithmetic-Mathematics Test (Vernon & Miller, 1976). The study was interested in the attainment levels of the hearing impaired students in comparison to hearing students of the same age. Again the raw scores of the test were converted to 'mathematical ages' and comparisons were made on the basis of this. The average mathematical age was 15.5 years for the normally hearing subjects and 12.3 years for the hearing impaired students. The mean mathematical age in the hearing impaired sample varied as a function of the type of school the pupils attended. The deaf students in special schools for the deaf were 3.4 years behind their hearing peers with a mathematical age of 12.1, the deaf students attending schools with units were 2.7 years behind (i.e. a mathematical age of 12.8). Those hearing impaired pupils who attended mainstream schools were 1.5 years behind their hearing peers, obtaining a mean mathematical age of 14.

Throughout the 1980s Heiling (1995) administered written mathematical tests to deaf students attending a school for the deaf in Sweden. The main aim of the study was to assess whether there had been an improvement in attainment from the 1960s to the 1980s. It was hypothesised that the change in communication policy in Swedish educational establishments for the deaf from oral to signed methods would raise the overall proficiency demonstrated in mathematics. The results of this aspect of the study will be covered in more detail later on in the chapter. However, Heiling (1995) also compared the deaf students' performance with the test norms, based on the performance of hearing children in the 1960s. The maths tasks administered involved the 'four rules' of arithmetic and sums with missing numbers, for example '_ + 8 = 10' where the task was to write the correct numbers in the spaces. In comparison to the 1960s norms the 40 hearing impaired students performed below the average levels of equivalent grades in three of the four tasks. These were in 'addition (grade 8), 'multiplication (grade 8)', and the missing numbers task 'R16C (grade 8)'. The only sub-test on which the subjects achieved levels that were comparable to the norms was the 'arithmetic (grade 9)' task.

In Norway, Frostad (1996) administered computational assessments to hearing and hearing impaired children aged from 7 to 16 years (grades 1 to 9) in 1993 and 1994. The 246 hearing impaired children taking part in the study attended mainstream, special and unit based schools. The results obtained by the hearing impaired children were compared to 557 hearing children administered the assessments at the same time. The children were administered 'age-relevant' computational tests. The mathematics test administered to the children in the first to fourth grades were a published series (Tornes, Rusten & Hagen, 1980). The tests for the children in grades 5 through to 9 were developed specifically for the study and were based on the national mathematics curriculum. The assessments were considered to be 'almost' non-verbal and included problems concerning addition, subtraction, multiplication, division, algebra, fraction, measurement and equations. Again, as with the previous research, the hearing impaired children obtained lower mean attainment levels than their hearing peers.

Nunes and Moreno (1998) presented the NFER-Nelson 7-11 series of mathematics assessments to 85 hearing impaired children in schools year 2 through to 5 in special schools and units around London. The mean standardised score obtained was more than two standard deviations below the published mean of 100. Even if the children whose scores were classified as 'extremely low' according to the assessment manual were excluded, the mean standardised score remained low, 83.4 this was equivalent to the 13th percentile. The range of scores when excluding the children with 'extremely low' score was from 70 to 120 – the 2nd to 91st percentile respectively.

2.2.2 Distribution of scores

As well as reporting the average levels of achievement, studies have also reported the range of scores obtained by the hearing impaired sample. It has been argued that quoting and comparing the mean scores obtained by hearing and hearing impaired groups provides an incomplete picture. For example, Heiling (1995) identified a tendency for the results in the multiplication, addition and the missing numbers sub-tests to be polarised; so that quoting the group mean would be misleading. It was revealed that just under half of the subjects obtained results which were equivalent to or above the average hearing norms, whereas the other students performed well below this level. Forty students took the test in the 1980s, in the 'addition' and the 'multiplication' tasks 4 of these pupils obtained scores described as 'extremely poor' in both the tasks. The number of students who obtained results which were equal to or better than the average hearing 8th grader was fourteen in the addition task, fifteen in the multiplication task and seventeen in the missing numbers task.

The distribution of scores of those students taking the Graded Arithmetic-Mathematics test in the study carried out by Wood *et al.* (1986) depended on whether the deaf students were taking the 'senior' or the 'junior' version of the test. Those students taking the 'senior' version of the test performed similarly to their hearing peers. However, the deaf students taking the 'junior' version of the test performed less well than the hearing children taking the 'junior' test and the hearing and deaf students taking the 'senior' version of the test. In addition, Wood *et al.* (1986) reported that 15% of the hearing impaired sample achieved maths ages at, or above, their chronological ages.

Frostad (1996) found that 37.5% of the hearing impaired sample obtained scores that were equal to or higher than the means obtained by their hearing peers. In addition to this, Frostad (1996) examined and compared the scores of the children at both extremes of achievement, those achieving the highest and the lowest scores. When the scores obtained by those children in the top twenty percent in both the hearing and hearing impaired groups were compared, it was found that the scores were comparable and not significantly different. When the scores obtained by the children in the bottom twenty percent in both groups, it was found that the hearing impaired children obtained significantly lower scores at all grade levels.

These studies demonstrate that there is a large minority of hearing impaired students capable of performing at levels that are comparable to hearing students of the same age. However, there is a difference in the percentage of students who are reported able to obtain these levels. The higher levels reported by the Heiling (1995) could be as a result of the use of norms which are twenty years old. The norms and attainment levels of children in assessments are changeable and so the direct comparison of the Swedish 1980 sample with a 1960s hearing sample is debatable. However, Frostad (1996) also reports a greater percentage than the Wood *et al.* (1986) study. Direct comparisons between the studies are not really possible because they deal with different tests administered in different countries to sample of deaf students, since they were oral in one study (Wood *et al.*) and signing in the others (Heiling, 1995; Frostad, 1996). These differing percentages raise the question as to whether the standards of mathematical attainment are improving in the hearing impaired population.

2.2.3 Hearing impaired children's mathematical attainment over time

The changes in the proficiency of hearing impaired students in mathematics over time has been examined by comparing the performance of different samples of hearing impaired students taking the same test at different times. Heiling (1995) compared the results of the students taking the tests in the 1980s with hearing impaired students taking the test in the 1960s.

Table 2.1 Mean scores of hearing impaired students taking mathematical assessment in the 1960s and 1980s (adapted from Heiling, 1995)

Task	**1960s (n=104)**	**1980s (n=40)**
Addition (grade 8)	31.9	32.6
Multiplication (grade 8)	22.1	28.3
Arithmetic (grade 9)	18.7	22.8
Missing number (grade 8)	9.7†	12.0

Note: † from one year in the 1960s only.

Analysis of the scores obtained by the students in the 1980s and 1960s found the differences between the means were significant in all the sub-tests ($p<0.01$) except addition, with an improvement in scores in the 1980s. Heiling (1995) attributed the higher scores in the later administration of the test to the change in communication policies that had taken place in Sweden, from Oral to Signed communication. However, the differences in the scores could also be attributed to other factors. Firstly, the assessments given in the 1960s and 1980s were not exactly the same. In the 1980s the test was adapted to include some more 'modern' items, the extent of the adaptation was not described in full but this may have had an impact on the final scores in the 1980s. In addition, the impact of changing the communication methods in schools could also have had the indirect consequence of changing the curriculum and the teaching methods. Thus, the differences in performance could be explained by changes in curriculum content rather than the direct consequence of changing communication methods.

Comparisons of the performance of hearing impaired students taking another Swedish assessment was reported by Balke-Aurell (1988; cited in Heiling, 1995). The Swedish labour market administered tests that were aimed at helping students to make further educational choices. The aim of the study was to examine whether there were differences in the results obtained by the hearing impaired students over time. The means and standard deviations of the students in 9th and 10th grades in the school years 1976/77 through to 1986/87 were calculated. Balke-Aurell (1988) divided the sample of students into two groups, those who were tested in the years 1977 to 1981 and compared these results to those tested in the years 1982 to 1987. Balke-Aurell (1988) found a 'tendency' for the results to improve in numerical and inductive tests in the tests that were administered later. However, Balke-Aurell did identify some problems with the interpretation of these results. Firstly, in some years there was much missing data because not all the pupils were obliged to take the test, thus endangering the analysis due to internal dropout and bias in the sample. Many of the deaf students in the 1970s were deafened because of a rubella epidemic during the 1960s. This would have had the effect of lowering the mean in the former sample because rubella can be associated with other neurological problems that could affect learning.

In the United States, Allen (1986) compared the results of a hearing impaired sample taking the Stanford achievement test from the two years 1974 and 1983. The scores were obtained during the norming of the sixth and seventh edition of the Stanford Achievement test on a sample of students aged 8 to 18 years attending special education programmes. Generally, the results showed an improvement in mathematical and language sub-tests over time. There were, nevertheless, difficulties with the analysis because there were ambiguities over the validity of the score conversion tables between the two editions of the test. There were also differences in administration over the two years. In addition to this, some of the students who had taken the test in 1983 had taken the test previously in its piloting; this could have biased the sample. Allen (1986) acknowledged these difficulties but still concluded that there had been an improvement in performance by students taking the test in 1983. However, the inability to compare the results directly and quantify these differences makes such a conclusion hazardous.

This problem was addressed by Frostad (1996) who administered the grade appropriate test twice, first at the age-appropriate time and then again a year later. These assessments were administered to the hearing children in grades 5 through to 8 and to the hearing impaired in all the grades. In this way it was possible to obtain a measure of absolute achievement over the period of one year. Again, it was possible to compare the hearing and hearing impaired groups. Throughout all the grades the scores of the hearing children increased significantly in the mean absolute achievement from the first to second administration. This was not the case for the hearing impaired children. Although all the grades obtained a higher mean score at the second administration, the increase was only significant for the children in grades 1, 2, 3 and 7.

In summary, it has been found that, on average, the deaf obtain lower scores than hearing peers. However, these same studies also show that there are deaf children who can obtain scores that are comparable to standards and norms based on hearing children. Those studies that have attempted to establish whether the standards in mathematics attainment have improved amongst the deaf have been inconclusive. Frostad (1996) notes that there are very strong cohort effects with hearing impaired samples because the variety that is found between and within hearing impaired groups can range greatly. Even if the groups vary just in the causes of hearing impairment this could have the consequence of altering academic achievement, as was highlighted in the Balke-Aurell (1988) study. Further studies would have to attempt to investigate this further.

2.3 Explanations for lower mathematical attainment

Having established that the hearing impaired obtain lower attainment levels in mathematics, research has attempted to identify the causes for this underachievement. It has been found that the hearing impaired population perform as well as the hearing in assessments of non-verbal IQ (e.g. Braden, 1994), so lower intellectual ability in the hearing impaired cannot explain this discrepancy. One line of inquiry has explored the association between mathematical ability and the demographic variables associated with hearing impairment. The second has investigated relationships between the number processing skills of the deaf and their mathematical ability.

2.3.1 The association between achievement and demographic variables?

Research in this field asks whether there is something specific about being hearing impaired that hinders performance in mathematics. Research here uses the heterogeneity of the hearing impaired population to explore within-group differences. Certain groups of hearing impaired students can be compared with others to explore whether performance differs as a result of these group differences. For example, deaf children with deaf parents have been compared to deaf children of hearing parents on a number of cognitive and academic assessments (e.g. Conrad & Weiskrantz, 1981).

Jensema (1975) examined the relationship between the scores obtained in the 1973 version of the Stanford achievement test and demographic variables. This version of the test was administered to over six thousand students enrolled in special educational programmes for the hearing impaired. The following demographic variables were analysed: age; sex; cause, degree and onset of hearing loss; 'additional handicapping conditions' (specific types and number); ethnic background; and type of educational programme. These variables were categorical and the means for each of the categories were compared, throughout the analysis only age was controlled for.

Those students reported as having an inherited cause of hearing loss had scores which were superior to those with other reported causes, excepting mumps and otitis media which are usually post-linguistic causes of hearing impairment. Those subjects born prematurely or who had suffered from birth trauma scored below the mean in the mathematical sub-tests.

Generally, as hearing loss became more severe the performance on the tests declined, this was most apparent in the language tests and least apparent in the 'mathematical computation' sub-test. The presence of additional handicapping conditions lowered the scores of the subjects, and the scores decreased further with the increasing number of handicapping features present.

The type of educational programme was also examined, mean scores obtained by those attending different types of schools were found to vary. However, Jensema (1975) stated that this could be as a direct result of the type of children enrolled in the programmes. For example, the lower scores obtained by those pupils attending day schools could be expected because, at the time of the study, those children with additional handicaps were more likely to attend day school programmes for the deaf.

Although within group differences were found it is not possible to draw conclusions because the study only compared the differences from the mean within the variables. No further analysis was performed to establish whether the differences reported above were statistically significant or explained mathematics attainment.

Wood *et al.* (1983, 1984, 1986) attempted to examine the effect of different variables on the performance of mathematics using more detailed statistical analysis. The main demographic variables considered by Wood *et al.* (1986) were - the severity of hearing loss and the type of school attended. If there was a direct effect of hearing loss on mathematical ability then Wood *et al.* (1986) hypothesised that the lower mathematical scores would be obtained by those with the most severe hearing losses. A correlation between degree of hearing loss and scores on the Vernon-Miller test revealed that an increase of hearing loss was only 'marginally correlated' with a decrease in mathematical attainment ($r=.13$; $p<.008$). Although this appears to support the idea that the more deaf a person is, the less able they will be in mathematics, this only accounts for 1.7% of the variance in mathematical achievement. Severity of hearing loss, then, was not a good predictor of mathematical age. This indicates that there are additional factors which affect the hearing impaired students' abilities in mathematics.

Another analysis addressed the issue of a possible ceiling effect on performance that was dependent on the severity of hearing loss. In Wood, Wood, Griffith and Howarth (1986) the degrees of hearing loss were re-coded into 10 dB bands. If there were a ceiling effect on the scores then one would expect that those with the most severe hearing losses would achieve the lowest 'highest' scores. No correlation was found between the highest scores obtained and the degree of hearing loss. When the same analysis was repeated with the lowest scores obtained, a correlation was found. The more severe the hearing loss the lower the 'lowest' scores obtained. It was suggested that although hearing loss did not necessarily impede a child from performing well in mathematics, it could exert an influence on mathematics learning, particularly at the lower end of the scale.

The effect of the different types of schools the hearing impaired children attended was examined. The mathematical ages of the hearing impaired children varied as a function of the type of school attended. Those attending the special schools obtained a mean mathematical age of 12.1, those attending the units for hearing impaired children obtained a mean mathematical age of 12.8 and the hearing impaired who attended mainstream schools obtained a mean mathematical age of 14. It was hypothesised that the differences in attainment by school type could be as a result of the differing amounts of time spent on the maths curriculum in the different types of schools. The relationship between maths scores and the school 'type' was investigated further.

Initially, a comparison between hearing impaired children attending special schools and schools with units were made. Wood *et al.* (1984) reported no significant difference in maths scores between the 271 students who attended the special schools (hearing loss 92dB) and of the 143 students who attended the units (hearing loss 68dB). However, the difference in hearing loss between the two groups was highly significant ($p<.001$). Moreover, there was a group of children attending a special school for the deaf who obtained maths ages which were equivalent to the mainstreamed (and significantly less deaf) children.

Children with similar levels of hearing loss attending different types of schools were compared. It was hypothesised that if the educational experience was an important factor, then those attending mainstream schools would obtain higher scores even though the degree of hearing loss was the same. A group of children from different educational backgrounds with hearing losses ranging form 50 to 70 dB were compared. No significant differences were found in attainment in this group as a function of type of school attended.

Lastly, a multiple regression analysis was performed using the three predictor variables of sex, school placement, and degree of hearing loss. These three predictor variables together only explained 8% of the variance in maths score. After school placement was removed from the model there was no significant decrease in the amount of variance explained. Wood *et al.* (1986) concluded that, ' ... school background was not a significant factor per se. Hearing loss accounted for nearly all the differences between the mainstreamed children and those from special schools ... (p. 153)'. Moreover, Wood *et al.* (1984) concluded that '... the major determinants of mathematical ability in hearing impaired children must lie outside the factors explored here ... (namely: sex, school placement and degree of hearing loss, p. 258)'.

The analysis of the relationship between the demographic variables has had limited success in explaining the differences in attainment between hearing and hearing impaired students. An alternative research strategy has considered numerical processing skills as a potential cause of lower mathematical ability in the hearing impaired.

2.3.2 Number processing skills

As summarised in the previous chapter, memory processes of the hearing impaired differ to those of the hearing participating in the same studies (e.g. Hermelin & O'Connor, 1972; MacSweeney, Campbell & Donlan, 1996). The memory capacities have been found to be smaller in the hearing impaired and there is a reliance on alternative coding strategies. More importantly, there is evidence of less reliance on verbal strategies such as vocalisation. This led to the hypothesis that these processing differences may also be applied when completing mathematical tasks, explaining the lower performance by the hearing impaired.

A study by Hitch, Arnold and Phillips (1983) compared the processing skills of hearing and deaf children. The aim of the study was to examine the different ways that the deaf and hearing students might find solutions to addition problems of the type 'm + n =?' It was hypothesised that the hearing subjects would reconstruct the problem by covertly counting on from the larger of the two addends in a number of steps equal to the smaller number. Groen and Parkman (1972) based this counting model on observation in a study with normally hearing 7 year olds. In contrast with this, it was hypothesised that the deaf students would not display the same response pattern because the deaf find oral skills more difficult than hearing participants and so would consequently employ an alternative to the counting on strategy to solve this type of problem. It was proposed that the hearing impaired participants would use long term memory to retrieve number facts.

The deaf and hearing students were matched on arithmetical achievement and presented with sums which they judged to be right or wrong. The response time was recorded and these were examined to establish whether they fitted the counting model put forward in the hypothesis. It was found that the 'counting on from the larger number' model (MIN model) provided the best fit of response for a greater number of subjects in both the deaf and hearing groups.

Mulhern and Budge (1993) re-examined the hypothesis that inferior attainment in mathematics was related to the absence of vocalisation and sub-vocalisation when performing mental arithmetic. Mulhern and Budge (1993) criticised the Hitch, Arnold and Phillips (1983) study on a number of points. Firstly, the deaf children were, on average, 4 years older than their hearing counterparts. Secondly, the deaf children were orally trained and had scored highly on a written test of mathematical achievement. The deaf group was matched, on the basis of this test, to hearing subjects. Mulhern and Budge (1993) questioned whether this group was really representative of the hearing impaired population since previous studies have shown that the average attainment of the hearing impaired student in mathematics is lower than that of hearing students. Mulhern and Budge (1993) also questioned the procedure of the experimental task, arguing that an open-ended choice response was more appropriate than a two-choice verification procedure.

The procedure in Mulhern and Budge's (1993) study differed slightly to the Hitch *et al.* (1983) study. Ten prelingually, profoundly deaf subjects aged 11 to 13 years from a school from the deaf and ten hearing controls (of roughly the same age) were required to solve 100 addition combinations presented on a computer. The responses and the response times were recorded. The response times were then fitted to a counting model. It was found that, for 9 of the 10 hearing subjects and for 8 of the 10 deaf subjects, the MIN model provided the best fit. The best fitting models for the remaining subjects were SUM (counting all) and Y (counting on from the first number) both developmentally immature models.

Although the Hitch *et al.* (1983) and the Mulhern and Budge (1993) studies differed both in procedure and in the communication mode of the deaf subjects, the two studies revealed similar results. Although the response times of the deaf were generally slower than those displayed by the hearing children, Mulhern and Budge noted that '... a striking feature of the study is the marked similarity in patterns of response for the deaf and hearing children...' (p. 59). Mulhern and Budge (1993) also concluded that although the models providing the best fit the same for both groups of subjects in their study, this does not demonstrate whether the subjects, hearing or deaf, actually employed sub-vocal or other strategies to solve these addition sums.

Epstein, Hillegeist and Grafman (1990) examined the number processing skills of deaf college students who were users of ASL and of hearing college students. It was reported that the lack of ability of hearing impaired students has often been explained by a lack of preparation for the task, English language deficiencies and limited experience with abstract-reasoning and problem-solving tasks. Epstein *et al.* (1990) investigated whether differences in number processing skills could explain the difference in ability. A series of tasks previously administered to normally hearing participants were presented to hearing impaired and hearing students. The tasks relied on knowledge and skills which were '... if anything, overlearned...' by the deaf students and did not rely on language. For these reasons it was hypothesised that there should be no differences in accuracy and response times between the deaf and hearing subjects on these tasks.

Three tasks were presented to the hearing and deaf subjects. The first was 'magnitude comparison', here the task was to judge which of two numbers between 1 and 99 was larger. The second task was called 'calculation verification'; the given result of an arithmetic problem had to be assessed as correct or incorrect. The last assessment was a short-term memory task; this required the subjects to judge whether a single probe digit was a member of a previously presented stimulus set. The responses and the response times were recorded. The deaf and hearing students performed all the tasks accurately and showed similar patterns of response times. In the magnitude comparison task, for example, it took all the subjects longer to identify which of the two numbers was larger when they spanned across the decade, rather than when the two numbers were single digits. In the calculation verification task, it took all the subjects longer to verify the correctness of division and subtraction sums than addition and multiplication sums.

Although the hearing and deaf subjects displayed similarities in performance in all three tasks, there were some differences. In the memory span task the deaf subjects showed a drop in accuracy rate when the stimulus set of digits was increased. They demonstrated a 99.1% accuracy rate with a one-digit stimulus set and an 82.4% accuracy rate with the six-digit stimulus set. The accuracy rate in the hearing subjects did not drop below 90%. Although the differences were not statistically different, Epstein *et al.* (1990) suggested that the drop in accuracy rate in the deaf subjects could be indicative that five- and six-digit stimulus sets begin to tax the memory capacity of the deaf subjects more than the hearing subjects.

The average response times in all the tasks were also different for the hearing and deaf students. The deaf students were significantly slower than the hearing students were. This was consistent with previous findings in the research concerning the memory abilities and strategies of the hearing impaired covered in the previous chapter. The response times in the study were measured in milliseconds, and although the deaf showed consistently slower response times, the differences in mean response times between the hearing and deaf for each task presented were rarely more than a second long. The task which identified the largest differences in response times between the hearing and deaf subjects was the calculation verification task. Indeed, this was the only task where the differences between the hearing and deaf subjects' response time were over one second long.

Table 2.2 Mean response times (and the difference) in milliseconds for hearing and deaf subjects in the calculation verification task (adapted from Epstein *et al.*, 1990)

Sub-task	**Hearing**	**Deaf**	**Difference**
Addition	1,200.2	1,968.3	768.1
Subtraction	1,383.5	2,547.1	1,163.6
Multiplication	1,209.9	1,921.8	711.9
Division	1,435.8	2,474.5	1,038.7

Although the response times were significantly different, it is not clear how this difference of one second or less in processing number could have an impact in general mathematical attainment. The three studies described above, although finding differences in the speed of response time in the different tasks, have found little differences between the hearing and deaf subjects in other respects. This suggests, in terms of accuracy at least, that if the deaf and hearing are processing number differently, that their (hypothetically) different methods are equally efficient.

Attempts to find causal explanations for the lower achievement in hearing impaired children has thus far been limited. One reason may be the assumption that all hearing impaired children underachieve in mathematics. Analysis of the distribution of mathematics scores has found that this is not necessarily the case (Wood *et al.* 1986). Recent research has pointed to a variation attainment as a function of differences in the delivery of the mathematics curriculum.

2.3.3 Delivery of curriculum

Allen (1990) and Pagliaro (1998) both administered surveys to teachers and administrators in deaf education. Allen (1990) administered his survey in Britain and Pagliaro (1998) administered her survey in U.S.A. Allen (1990) surveyed teachers of the deaf and examined the practices and attitudes towards teaching mathematics in comparison to teaching language. Among the questions asked were the number of hours spent teaching maths, mathematical qualifications obtained and how much the teacher liked teaching maths. Allen (1990) found that, in comparison to the general population of teachers teaching in mainstream schools, there were fewer maths specialists in deaf education. The majority of the teachers taking part in the study were more interested, and preferred, teaching language to maths. When children's attainment levels were compared in special schools with and without maths teachers, the children in schools with maths teachers achieved significantly higher results. This suggests that the presence of a qualified teacher can have an impact on deaf children's mathematical understanding.

Pagliaro (1998) explored whether the educational reform of the mathematics curriculum in mainstream education had had an equivalent impact on maths education for hearing impaired children. A survey was sent to administrators and teachers in deaf education asking about their awareness and knowledge of the reform and their current teaching practices. Questions about educational reform included knowledge of three documents published by the National Council of Teachers of Mathematics (NCTM). The documents advocate teaching methods based on a constructivist philosophy; where knowledge is built through active participation using concrete materials and technology as tools to enhance and expand the learning environment. Pagliaro (1998) compared this awareness and knowledge of the reforms to actual teaching practices. Teachers of the deaf did show some awareness of the NCTM documents, but not as much as teachers in mainstream education. With reference to teaching practice, it was found that implementation of reforms was inconsistent. Some teachers did include occasional practices consistent with reform recommendations such as problem solving and using computers, but there was also a high frequency of traditional teaching methods such as 'drill and practice' and 'memorisation of facts' exercises. This frequency was so high that it appeared to be the only form of instruction in some establishments. There also appeared to be indications that American teachers of the deaf may also lack confidence in teaching mathematics in comparison to language. For example, one recommendation by the NCTM is to include mathematics into other disciplines taught in the curriculum. Many teachers commented that they 'lacked both the time and the knowledge' to do this successfully. These studies, based in different countries, paint a picture of maths education provision for the deaf that is inconsistent; curriculum and teaching practices varying from school to school. It appears that children who are taught by teachers who are confident with mathematics themselves achieve higher standards (Allen, 1990). It may be that these teachers are the ones who manage to communicate mathematical ideas more effectively. This, however, has not been explored directly. The teaching methods of 'specialist' teachers has not been examined and compared to 'non-maths specialist' teachers.

2.3.4 Summary

The research thus far has provided limited explanations as to why hearing impaired children underachieve in mathematics. There may be a number of reasons for this. Firstly, this research has focused on children who are assumed to have already acquired the basic mathematical concepts. Secondly, an assumption has been made that all hearing impaired children obtain lower maths scores. As mentioned previously, this is not necessarily the case. Thirdly, a causal relationship between hearing impairment and mathematics attainment has been explored in much of the research. In fact, the evidence does not support a causal relationship. The finding that a large minority of hearing impaired children obtain comparable scores to hearing children in assessments together with the higher attainment levels obtained by those children taught by teachers confident in mathematics goes against a causal hypothesis. To the contrary it suggests that many hearing impaired are risk of failing because their needs are not being met in the mathematics classroom. If these children are indeed at risk, then an alternative approach for assessing why they fall behind is required. It is suggested that a developmental perspective would be appropriate for investigating this. This approach could compare the numerical development of hearing children and assess whether hearing impaired children develop along the same path. An examination of how hearing impaired acquire mathematical concepts and the difficulties they could encounter in the acquisition of the concepts could reveal why some children lag behind their hearing peers in assessments of mathematics attainment. The following section explores this perspective in more detail.

2.4 The development of numerical concepts in hearing impaired children

The focus of the section is to explore the development of mathematical concepts in deaf children. This is achieved by comparing what is known about the development of numerical concepts in the hearing impaired to the literature based on hearing children. The aim of examining this development is twofold. Firstly, to establish whether hearing impaired children develop along the same path as hearing children. In this way it can be established whether the hearing impaired experience a delay in the development of mathematical concepts, or whether their development is qualitatively different. Secondly, by examining the roots of mathematical understanding it should be possible to identify if, and where, specific difficulties may emerge for hearing impaired children. Throughout the section, issues that have been raised in research about development of mathematical concepts in hearing children are discussed. The aim of this is to inquire whether they are also relevant in the study of hearing impaired children learning mathematics. Research with hearing children is described in the following sections. The numerical concepts described include: how children learn to count; how they understand the numeration system; and the development of understanding about additive and multiplicative situations. Relevant research with hearing impaired children is described, and any differences or difficulties that they may experience are particularly highlighted.

2.4.1 Counting

Research in the acquisition of counting has focused on how children learn the counting sequence (e.g. Gelman & Gallistel, 1978) and how children learn when counting is an appropriate and useful tool (e.g. Fuson, 1988). Gelman and Gallistel (1978) put forward three 'how to count' principles. These are the 'stable order', 'one-to-one' and 'cardinality' principles. The 'stable order' principle states that the number tags or names must be generated in the same sequence for every count. The 'one-to-one' principle refers particularly to counting objects, and states that each item in the collection of objects being counted must be given only one tag. The 'cardinality' principle also refers to counting objects and refers to the observation that the tag used to count the last object in a collection refers to the total number of items in that collection. Although these principles have not been examined directly with hearing impaired children there is evidence to show that they display knowledge of them. Secada (1984) provides indirect evidence for the demonstration of knowledge and use of these principles by American hearing impaired children. Secada described the ASL (American Sign Language) counting string. He also investigated differences between oral English language children and native ASL signers in counting ability and understanding of numerosity and cardinality. The children were asked to perform a number of tasks that assessed their counting accuracy, understanding of the number string, and the use of counting.

2.4.1.1 Learning to count

Counting in English involves learning the names of the numbers and learning their correct sequence. The numbers under ten all have different and unrelated names, so learning to count requires learning and remembering these names in the correct sequence. After this there is a pattern in the numbers, which are generated from the first ten words. This could present difficulties for deaf children who are oral because there are numbers that sound similar (for example six, sixteen and sixty). This may result in errors in production and comprehension that could lead to confusion. This would make learning to count a process that takes longer for oral hearing impaired children.

Secada (1984) states that counting in sign differs to counting orally in more ways than the mode of communication. There are production rules in Signed counting, so the manual configuration of one number leads to the manual configuration of the next. Although both the oral and signed number systems are both base ten systems, the signed system is rule-bound in fives. Although Secada (1984) was describing the ASL signed system his observations are also appropriate to counting in BSL. In BSL the numbers are also grouped in fives and similar production rules are observed (see figure 2.1).

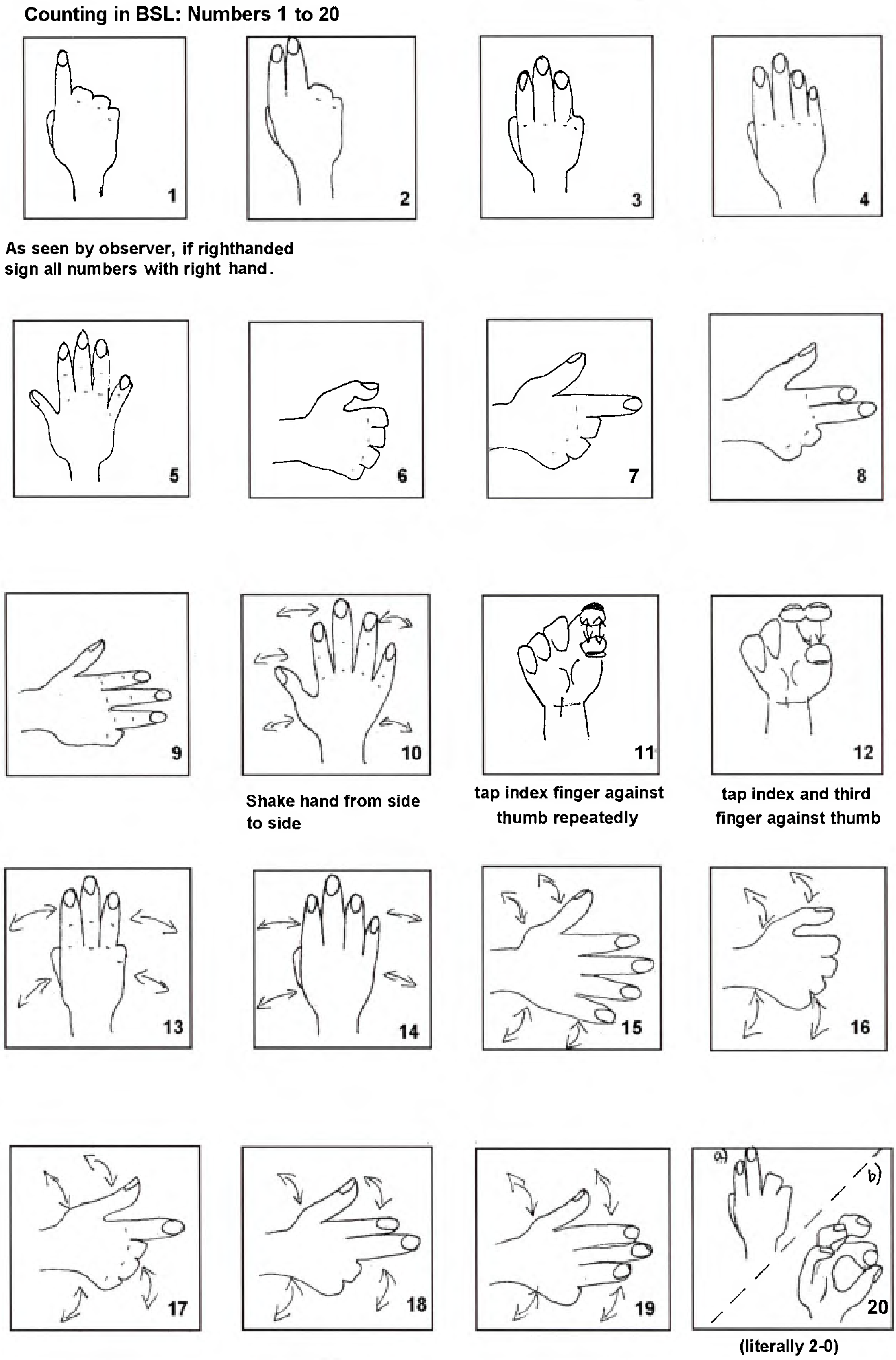


Figure 2.1 Counting in British Sign Language

In Secada's study, native ASL signers (aged 3 to 7) were matched to hearing oral children on the basis of age. The children were compared on counting ability and accuracy. Secada examined differences in accuracy and use of counting between the hearing and signing children. If differences were observed, Secada hypothesised that they would be as a direct result of the linguistic differences and the presence of a production rule in the signed counting system. If there were errors in counting, for instance, then one would expect the hearing children to make acoustic errors and the signing children to make mistakes on the basis of hand shapes.

The children were assessed on counting accuracy and understanding of the numeration system. In the counting accuracy task the children were asked to count different arrays of unevenly spaced dots. Assessment of the children's understanding of the numeration system required the children to complete a number of tasks. 'Number string' required the child to count to their highest number. 'Counting to x' required the child to count to a number specified by the experimenter. The task 'And next' required the children to state the number immediately following that mentioned by the experimenter. 'Counting forward from x' required the child to count on from a specified number, and lastly the children were asked to count backwards from the highest number he or she had reached during the 'number string' trial. When these children were compared on the basis of development of numbers (proficiency in counting); Secada found an age lag in the hearing impaired group. That is to say, it took the signing children longer to become proficient counters.

The hearing and deaf children were then matched for rote counting ability and age. An analysis of the tasks assessing understanding of the numeration system was made and there were no significant differences between the hearing and deaf children on all except one of the tasks. The deaf children performed significantly better than the hearing children in the 'And next' task. Secada stated that these results were as a direct result of the production rules in the ASL counting system. Secada argued that this could also explain the longer length of time it took for the deaf children to become proficient at counting. Counting for the signing children would require understanding the rules of Signed counting as well as producing the numbers.

2.4.1.2 Knowing when to count

After assessing the accuracy of counting, Secada asked whether the children knew when to use counting to solve tasks. The use of counting was assessed with the following tasks: a comparison of two rows and the production of an equivalent set of counters. In the comparison task, the children were asked whether two lines (one red, the other blue) contained the same number of dots. The lengths of the rows were varied so that the equivalence judgements could not be correctly made based on length of the row alone. This task was administered in two conditions. In one condition, the child was asked to judge the rows and no further instruction was given (called the spontaneous count condition). In the other condition the children were given an explicit instruction to count the dots in the rows before making their judgements. If the children realised that counting was a useful tool to use prior to making a judgement, then they would use it in the spontaneous count condition of this task. In the production of an equivalent set the children were required to produce a number of counters. This was asked in two ways. In the first they were shown an array of counters and asked to make the 'same' number. In the other the children were asked to give a specified number of counters. The aim of this task was to see whether the children counted to ensure that they had placed the correct number of counters.

Comparison between the performance of the hearing and deaf children on the use of counting tasks revealed no differences except on two instances. When the children were asked to make an equivalent set based on the picture, the deaf children performed better than the hearing children did. However, when asked to make a judgement about the equivalence of the rows in the spontaneous count condition, the deaf children behaved in a way that had not been previously noted in the literature. Fifteen of the 21 deaf children made their judgement on the basis of the colour of the row, while only 2 of the 15 hearing children made their judgement in this way.

The signing children obtained higher scores when producing an equivalent set of counters from a drawing. Secada stated that these results could be explained by the nature of the sign for 'same', which could have encouraged the children to match the counters from the picture exactly. This suggests that they did not use counting for either production or the equivalence tasks. This casts doubt upon whether the hearing impaired children in Secada's study had really understood the use of counting. As mentioned previously, fifteen of the 21 children behaved in this way. The children were also categorised on their rote counting ability. Those children who could not count above 20 were classified as 'low' rote counters and those who could count above 20 were classified as 'high' rote counters. Six of the deaf children were classified as 'high' rote counters. Secada does not say whether any of these six high rote counters made a judgement on the equivalence task based on colour. If only the low rote counters had made a judgement based on colour, then this could reflect their generally limited ability and understanding of counting.

If comparisons are made with research based on hearing children, such as Gelman and Gallistel's counting principles (1978), how do hearing impaired children compare? Secada's study seems to show that it takes the hearing impaired child longer to learn and master the counting system. However, once they have done so, the signing children demonstrated knowledge in two of the counting principles. The 'stable-order' principle was demonstrated by a proficiency in counting and the success in 'And next' task. The 'cardinality' principle was demonstrated by the tasks that assessed accuracy of counting. Secada's tasks did not investigate the 'one-to-one' principle but other observations of deaf children counting provide evidence for an understanding of this.

2.4.1.3 Counting objects

The 'one-to-one principle' requires that each object in the set be given one tag and only one tag. This is to avoid an object being counted more than once. Evidence demonstrating that children have an understanding of the one-to-one principle has come from observing their behaviour when counting. Baroody (1992), for instance, gives an example of a child who does not understand this principle and who 'simply spew(s) out numbers as they pass a finger over a collection...(p. 313)'. Another example given was of kindergarten children who were observed pointing at an object but who assigned either too many tags or no tags at all. A child who honours the 'one-to-one' principle realises that doing this will lead to errors in counting. This same child would then count a set of objects by pointing to an object and giving it only one number tag. Following this, the child would then point to the subsequent object and giving the next number tag and so forth.

Evidence of deaf children demonstrating knowledge of the 'one-to-one' principle would then also require that the child honour this pattern of behaviour while counting. This could be problematic for signing children in particular because they are already using their hands when they are signing. There is evidence (Fuson & Secada, 1977 cited in Secada, 1984) that signing children overcome this problem spontaneously. They simultaneously sign and point at the object with the same hand. In this way the children can keep a running tally of the objects being counted with high levels of accuracy.

2.4.1.4 Counting on

When children first begin to count a set of objects, or two sets of objects joined together, they do so by 'counting-all' the objects. In other words they, if asked to calculate 4 and 5 together, they count out 4 objects, then 5 objects and then count them all again to calculate the total. As children get older and more practised at counting, they begin to develop more efficient strategies for counting and develop a 'count-on' strategy. A child who counts-on would solve the same 'joining' problem by forming a set of five counters, and then a set of four counters. The solution would be obtained by beginning the counting from five while tagging the set of four counters ('six, seven, eight, nine').

It has been argued that the transition from counting-all to counting-on is an important developmental step. Nunes and Bryant (1996), for instance, state that this step could indicate the beginnings of the understanding of addition and the numeration system. They argued that addition, rather than one-to-one correspondence, provides the basis of understanding the properties of systems with a base. They based these arguments on a number of studies that investigated the relationship between knowledge of the number system with counting and addition tasks (Kornilaki, 1994; Wang, 1995). Knowledge of the number system was assessed with a shop task, which involved children buying items with counters representing money. There were two conditions in the shop task; the first assessed one-to-one correspondence. Here the children were given counters with a value of one, such that paying for an item would involve giving the experimenter the correct number of counters. In the second condition the children were given counters of different denominations. Paying for an item would then involve giving the correct combination of differently valued counters. For example, paying for an item which cost 12p with counters valued at 10p and 1p would involve giving three counters, one valued at 10p and two at 1p. This would require the child understanding the additive composition of 10 and 1 and 1.

Kornilaki (1994) examined the association between counting and additive composition with Greek children aged 5½ to 6 years who were administered three different tasks. The three tasks were an addition task (with a hidden addend), a one-to-one correspondence task and the shop task. It was hypothesised that the ability to solve addition problems (tested by the hidden addend task) rather than the ability to count (tested with the one-to-one correspondence task) would be associated with the ability to solve the shop task (indicating an understanding of the numeration system).

In the addition task the child was required to add two addends, one of which was visible and other was hidden. They were shown a wallet and were told that a girl had 8 drachmas in her wallet and that she had been given 7 more. The children were then asked how much money the girl had. The aim of using a hidden addend was to block the use of a count-all strategy by ensuring that the child had a visual representation of the second addend but not the first.

Ability to solve the hidden addend task but not the one-to-one correspondence task was significantly associated with the ability to solve the additive composition task. The strategies used to solve the hidden addend question were analysed, and more evidence for the importance of counting-on emerged. Even though the hidden addend was set up to block the count-all strategy, it was possible to obtain a correct solution to the problem by representing all the drachmas (hidden and visible) through movement or counting out aloud. There were some children who obtained correct answers without depending on these strategies that required representing all the hidden drachmas. These children simply said the cardinal for the hidden addend (8) and went on to count the visible drachmas. In this case the cardinal was considered a sufficient representation of the money in the purse. All these children who just used the cardinal value of the set of invisible drachmas (i.e. counted on) were successful in the additive composition task. All the children, except one, who represented the hidden drachmas by counting aloud, were also successful in the additive composition task.

The counting-on strategy has been considered an important indication that hearing children have made an important transition in the way they represent problems. Evidence of hearing impaired children displaying the same skills and knowledge should indicate that they also undergo the same cognitive transition. Nunes and Moreno (1998a) examined the development of a count-on strategy in hearing impaired children and the steps towards understanding the numeration system. There is also other evidence that signing hearing impaired children develop an understanding of counting-on and go on to use this effectively as a calculation tool.

Nunes and Moreno (1998a) describe a signed algorithm that is based on the understanding of counting-on. Although the signed algorithm observed was used for calculating addition and subtraction operations, only the procedure for calculating addition will be described here. In the solution of the sum '7 + 2', for instance, the two addends are represented in sign (see figure 3.1), one number signed on each hand. Increments of one are added to the hand signing the larger number as the other hand signs decreasing values of numbers. The result of the addition is found on the hand where the values increased. Variations to this algorithm, which often emerges spontaneously, have been observed (Moreno, 1994) but essentially the system is the same. One hand serves to keep a tally of what is to be added in the operation and the other hand signs the cardinal on to which these numbers are added. As the cardinal was seen as a sufficient representation in Kornilaki's hidden addend task, so it can be seen as so in the signed algorithm.

Nunes and Moreno (1998b) presented the tasks administered by Kornilaki (1994) to hearing impaired children. The purpose of administering the tasks was to examine response patterns, and to examine whether hearing impaired children showed similar developmental steps towards the mastering of the additive composition of number. It has been observed that hearing children develop intermediary strategies to solve the shop task. These are similar to the strategies used in the hidden addend task, for example if a child has to calculate the total of a 5p counter and four 1p counters. Some children did not count on from 5, but counted to five on their fingers and then went on to count the remaining four 1p counters. With practice, and as the task progressed, the children often abbreviated the counting process and began to count on from five. These observations indicate that both hearing and hearing impaired children go through the same process of external, gestural representation which makes explicit the numbers implicitly contained in the total. In other words, 1, 2, 3 and 4 are implicitly contained in '5'.

The task assessing understanding of the numeration system has also been found to be a significant predictor of performance in standardised mathematical assessments in hearing children (Nunes, Miranda & Silva, 1991). Nunes and Moreno (1998b) also explored the relationship between the shop task and formal mathematics attainment with hearing impaired children. The hearing impaired children were not as proficient in the task as hearing children, not all the year 5 children (aged around 10 years) were able to complete the task. However when the relationship between the two tasks was analysed using a multiple regression analysis. It was found that the shop task was a significant predictor of the standardised test scores. It explained 24% of the variance - even after controls for year group, degree of hearing loss and use of signing in the home were entered into the equation.

2.4.1.5 Summary

When deaf children count and use counting, they display the same development of counting skills as hearing children. Even in these early stages of number development one can see where the hearing impaired child may already experience difficulties and fall behind. Learning to count is a slower process for both the signing and oral deaf child. However, although these children may lag behind in the initial development of number, they still demonstrate an understanding of Gelman and

Gallistel's (1978) counting principles and of counting on. The evidence that young deaf children understand when to use counting as a tool is not so straightforward. However, one can presume, given that there is evidence for the more advanced development of counting-on strategies, that this is eventually mastered by hearing impaired children.

2.4.2 Additive problems

The study of word problems and their solution was first studied with elementary additive problems (e.g. Riley, Greeno & Heller, 1983). It became evident that problems requiring the same operation for their successful solution were not all equally simple to answer correctly. Nesher, Greeno and Riley (1982) compared the success of two subtraction problems in different schools. The first problem 'Dan had $10, how many dollars are left if Dan spent three?' had a success rate of 94% in school 1 (n = 967), 89% in school 2 (n = 222), 89% in school 3 (n = 256) and 85% in school 4 (n = 287). The success rates of the following type of question: 'John and Robert had 7 marbles altogether. Three of them were John's. How many were Robert's?' was 42%, 46%, 49% and 41% respectively. From these results they drew the conclusion that the operation to be performed, subtraction in this case, was not necessarily what determined the difficulty of a word problem. In fact, a number of variables were found to be significant in determining the difficulty of a problem. These included the semantic category of a problem (see table 3.1) and the location of the phrase describing the missing number. The order of the events described in the problem and the child's familiarity of the described situation also influenced a problem's difficulty. The following section will focus mainly on the position of the phrase describing the missing number.

Table 2.3 Semantic categories of additive word problems (examples taken from Riley, 1983)

Category	Relationship between variables	Example
Combine	Static, involves the combination of two sets.	'Joe has 3 marbles. Tom has 5 marbles. How many marbles do they have altogether?'
Change	Dynamic, described as an ongoing event and has a clear sequence with time.	'Joe had 3 marbles, then Tom gave him 5 more marbles. How many marbles does Joe have now?'
Additive compare	Comparison of one quantity in relation to another.	'Joe has 8 marbles. Tom has 5 marbles. How many more marbles does Joe have than Tom?'

The study of additive problems revealed that neither the operation to be performed nor the category of the additive problems fully explained the varying difficulties of word problems. Problems in the same semantic category were not all as simple to solve. It was hypothesised that the position of the phrase that described the unknown number was an important factor influencing a problem's difficulty. Hiebert (1982) explored this hypothesis and explored the nature of the difficulties. It was thought that those problems that were not easy to represent sequentially would be difficult to solve. By manipulating the position of the unknown number in problems in the same semantic category. Hiebert (1982) hypothesised that those problems where the result was unknown ($a + b = ?$) would be easier than both the problems where the first number was unknown ($? + b = c$) and where the second number or the change amount was unknown ($a +? = c$).

2.4.2.1 Solving additive problems

Hiebert (1982) gave six additive 'change' problems using small numbers to 47 first grade children from the USA. These children had no formal instruction in solving verbal problems or using objects to represent or model problem situations. The problems were varied and there were three joining and three separating problems. The position of the unknown was varied in each case. There were two result unknown problems (one joining and the other separating), two change unknown problems (one joining and the other separating) and two start unknown problems (one joining and the other separating). The problems were presented to each child in an individual interview; children had access to cubes on which they could model their answers if they wanted. The answers given and the strategies used to obtain the answers were analysed.

As expected, although the problems were all categorised as 'change' problems, they varied in difficulty. The problems with the first and second quantities unknown were more difficult than those with the result unknown. Analysis of the strategies used revealed that in the addition (joining) problems children either counted all or counted on using the blocks. In the subtraction problems the children used a wider variety of strategies.

It was observed that for the different types of change problems there was a tendency to implement different solution strategies. In the result unknown subtraction problems (a - b = ?) the 'separate' strategy predominated. The children tended to form a group of blocks that was equal to the larger number mentioned in the problem ('a'). They then removed the smaller number from this group and counted the remaining blocks. Carpenter and Moser (1982) also observed this strategy, although they called it 'separate from'. They described it as follows:

> Question: Pete had 6 apples. He gave 2 apples to Ann. How many apples does Pete have now?
> Separating from strategy: using objects or fingers, the child constructs a set corresponding to the larger given number in the problem (6). Then the child removes as many objects as indicated by the smaller number (2). The answer is the remaining number of objects (4).

A dominant strategy for the 'change - change unknown' problems (a - ? = c) was 'separate to'. The larger quantity ('a') was represented, then the blocks were removed until the quantity was equal to the smaller number mentioned in the problem. The answer was obtained by referring to the number of blocks removed.

In the start unknown problems for both addition and subtraction ($? \pm b = c$) there was a lack of dominant strategy and Hiebert (1982) thought that this probably reflected a confusion about how to represent or model these problems. This inability to represent these problems would also explain the low success rates.

Other strategies were also observed such as 'adding to' and 'count down', although they were not predominately used for any one type of question. The following example of 'adding on', also from Carpenter and Moser (1982), illustrates this strategy:

> Question: Pete had 3 apples. Ann gave him some more apples. Now Pete has 10 apples. How many apples did Ann give to Pete?
> 'Adding on strategy': the child constructs a set corresponding to the smaller given number (3). Then the child adds elements to this set until there are as many objects as indicated by the larger number (10). The answer is found by counting the number of objects added (7).

The examples given above, which were demonstrated by children in two different studies, show an ability to model situations described in the story. In these cases the children did not decide beforehand whether to implement an addition or a subtraction operation. The answers were obtained through their actions. The reliance on actions to model and eventually solve these problems explains why those word problems are difficult to model. The problems where the first and second numbers were unknown, were those that proved to be the most difficult to model, and consequently solve.

2.4.2.2 Deaf children solving additive problems

Word problems were administered to twelve Spanish, prelingually and profoundly deaf children aged 8 to 12 years old by Pau (1995). The aim of the study was to examine the extent to which reading comprehension influenced the problem solving competence in arithmetic word problems. The children taking part in the study were all educated in mainstream classrooms and were of average intelligence. The children were assessed for reading comprehension and on their ability to solve additive word problems. Three 'change' problems, 2 'combine' problems and 3 'compare' word problems were presented. Pau (1995) found that reading comprehension was 'clearly related' to the subject's problem solving level. Those students who achieved higher reading levels solved more of the problems. An analysis of the difficulty levels of each problem found that those questions that followed the chronological sequence literally were easier to solve than inverse problems.

Further analysis of the miscomprehension and errors made by the students revealed specific difficulties. The translation of 'more' in 'has more than' was treated as an addition, when it is not always the case. (e.g. 'Mary has 5 marbles. John has 8 marbles. How many marbles does John have more than Mary?' requires a subtraction for a correct solution). Another error found was that the children tended to ignore the comparative forms when they were reading, for example, 'have more than' was translated as 'have'. There was also confusion in the interpretation of 'some' with 'together'. In the sentence 'Together Mary and John have x marbles', some of the subjects understood that Mary and John each had x marbles.

These types of errors are not unique to deaf children. Research with hearing children describes similar errors and difficulties. However, these results show that even at an age where hearing children master these types of additive problems, they still seem to pose difficulties for hearing impaired children. The results of this study seems to indicate that the difficulties lie with linguistic ability, and that the hearing impaired demonstrate a lack of comprehension of the situations described in additive word problems. However, the literature with hearing children indicates that the solution of additive word problems is based, initially at least, on action. This finding gives reason to believe that hearing impaired children could also solve these types of problems if given objects with which to model the problems. Nunes and Moreno (1996) investigated whether hearing impaired children's success in solving additive word problems was dependent on the mediators used to solve the problems. It was thought that hearing impaired children would be able to solve additive word problems more easily if they could model and act out the problems than if they used a signed algorithm (described previously). In this study it was hypothesised that different materials would provoke different types of solution strategies. The objects could be used without having to decide previously whether an addition or a subtraction operation was required to solve the problem correctly. In contrast, when using the signed algorithm, the children had to decide previously whether the correct solution should be obtained with an addition or a subtraction.

A series of additive word problems were presented to a group of six hearing impaired children aged 6 to 8 years. Sixteen problems were presented in signed English in two situations: one with cut-out objects that represented the objects and people in the stories; the other condition where the solution relied on the signed algorithm. Previous to the testing sessions the same children were given a list of addition and subtraction questions to solve using any material desired such as unifix blocks or the signed algorithm. Those sums solved correctly by all or five of the children were included in the word problems. This was to ensure that any difficulties encountered were as a result of the problem situation and not the required sum. The children's comprehension of the problems was of primary importance during the testing sessions so the 'object' situation was presented first at the risk of biasing the results of better practice towards the signed algorithm session.

A variety of word problem types were administered to the children. A total of sixteen problems were presented to the children in each session. Four of the problems were 'equalise' problems. There were ten 'change' problems: three were 'result unknown' problems (one addition and two subtraction), four were 'change unknown' (two addition and two subtraction) and three were 'start unknown' problems (two addition and one subtraction). As well as this, there were two combine problems. The children were significantly more successful in the 'objects' condition than in the 'signed algorithm' condition (means of 9.45 and 1.98 respectively). The results were analysed further to examine where the differences between the conditions lay. It was found that those problems requiring a direct addition or subtraction for the solution were not significantly different across the conditions. One mistake was made by a child in the 'objects' condition and a different child made a mistake in the 'signed algorithm' condition. Other problems, such as the 'equalise' problems, were significantly different across conditions. The children performed well in the object condition (mean = 3.6), but not in the signed algorithm condition (mean = 1.0). The high success rate in the object condition could be explained by examining the solution strategies, such as for the following example:

> Question: At a party there were 6 children and five balloons. All the children want a balloon. How many children are sad because they haven't got a balloon?
>
> Solution: Child matches a cut-out child with a balloon until all the balloons have been matched, the answer is obtained by counting the number of children without a balloon. However, this same question did not translate easily to a formalised situation. The children in the study added the two numbers mentioned (6 and 1) without demonstrating any consideration for the situation. This explains the significantly lower success rate in the signed algorithm condition of the study.

The results of the study suggest that hearing impaired children can demonstrate an understanding of additive word problems if, like the hearing children, they can represent the situation described in the problem. Once the children have represented the problem, they are more likely to succeed in obtaining a correct answer. The discrepancy between the success rates of the children taking part in the study by Pau (1995) and the younger children taking part in the Nunes and Moreno (1996) study indicate that the hearing impaired children may, like hearing children, experience difficulties in moving from representing mathematical problems through action schema to more formal representations of mathematical problems.

2.4.3 Multiplicative problems

Those problems that involve multiplication, division and duplicating are all referred to as 'multiplicative' problems. There are different kinds of multiplicative problems and this chapter will follow the descriptions given by Nunes and Bryant (1996). They distinguish between those situations that involve relationships between sets or variables and situations that involve sharing and successive splits. The following section will describe the various multiplicative situations. Studies that describe some of the difficulties hearing impaired children face when dealing with multiplicative situations will then be presented. There is evidence that young children can reason about multiplicative situations. Research examining the strategies used by children in these studies will be described. There is no research examining the multiplicative strategies of hearing impaired children. For this reason, it will then be considered whether the same tasks used with hearing children could show similar findings with hearing impaired children.

2.4.3.1 Types of multiplicative problems

i. Co-variation and one-to-many situations

Situations that occur when two (or more) sets or variables are related can be distinguished in a number of ways. Nunes and Bryant (1996) distinguish between one-to-many and co-variation situations. One-to-many correspondence situations refer to the relationship between two sets, which are normally of discontinuous quantities, for example the constant relationship between one car and four wheels. A co-variation situation deals with a relationship between two or more continuous variables. Here the relationship between the variables is established either by convention, for an example an agreed price per kilo, or by causation, for example, the distance a car can travel on a litre of petrol.

The distinction between these two situations can be made on a number of levels such as the expression of the relationship and the reasoning required when working with either situation. In one-to-many situations the numbers expressed refer to the quantity of items in each of the sets and the relationship is expressed as a ratio. In co-variation the numbers refer to the value of the variables and the relationship is expressed as a third variable, 'price per kilo', 'kilometres per litre'.

Once the relationship had been established, manipulating the information to estimate what would happen to one set if the other increased or decreased would require different sorts of reasoning in the different situations. In a one-to-many situation one has to understand that the relationship between the sets will remain constant even if the numbers in the sets change. To maintain this relationship constant, one would have to increase (or decrease) the size of the sets by the same amount, which is called the scalar factor. This could be achieved by 'replicating', in the following example 'one car has four wheels, how many wheels are there with 5 cars?' The first set (cars) has been increased by five, so consequently the same action is required on the second set (wheels), resulting in 4 being added five times (20). Co-variation leads to another number meaning, that of the third variable mentioned previously, which is referred to as an intensive quantity. It refers to the relationship between the two variables and can be used independently to compare co-variation situations. For example, two cars can be compared on how far they can travel with one litre of petrol. Nunes and Bryant (1996) state that even if children understand one-to-many correspondence, they probably need to build some different concepts in order to deal with co-variation situations. This is because the relationship between the two variables could relate to the fractions of units of measurements, which arise when dealing with continuous quantities. The number meaning that expresses the relationship between the two variables is known as a 'factor', a 'function' or an 'intensive quantity'.

A distinction has been made between one-to-many correspondence and co-variation situations based on the different reasoning required. In reality, however, a single problem could be conceptualised (and solved) as either a one-to-many correspondence, or as a co-variation situation. Nunes, Schliemann and Carraher (1993) gave a series of proportion problems to two groups of subjects. The first group consisted of secondary school students, aged 14- to 21-years (mean age = 17.1) with 9 to 11 years of school instruction, in a fishing town in Northern Brazil. Their success rate and solutions were compared to fishermen in the same town (aged 15 to 63 years, mean = 36.4) with 0 to 9 years of instruction. All the problems were presented in interviews. The mathematics required to solve the problems was systematically varied, half the problems could be solved more easily using scalar (one-to-many) approach and the other half through a functional (co-variation) approach. The problems were about the relationship between weight of unprocessed and processed seafood. The aim of presenting these problems was to assess the extent of flexibility and reversibility the participants demonstrated when reasoning about multiplicative situations. An example of a scalar problem in the study was as follows:

> 'There is a type of oyster in the south that yields 3 kilos of shelled oyster for every 10 kilos you catch; how many kilos would you have to catch for a customer who wants 12 kilos of shelled oyster?' (p. 115)

A type of functional problem presented was as follows:

> 'There is a type of oyster in the south that yields 3 kilos of shelled oyster for every 12 kilos you catch; how many kilos would you have to catch for a customer who wants 10 kilos of shelled oyster?' (p. 116)

For each type of problem there were three types of solution: the functional solution, the scalar solution and school taught ('three rules') solution.

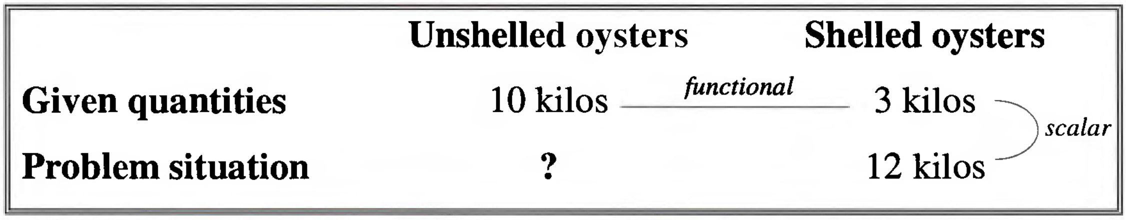


Figure 2.2 Example of Scalar problem given by Nunes *et al.* (1993)

If one uses a scalar solution, the relationship between one variable in the given and problem situations is considered. 12 kilos and 3 kilos of shelled oyster in the given and problem situations can be simplified to 4 kilos to 1 kilo. So 10 kilos of shelled would mean (10 x 4) kilos of caught oyster. An example of a scalar solution given by the respondents in the study was, "12 kilos gives 3 shelled kilos, so 36 kilos would give 9 shelled kilos. Add 4 to give 1 kilo, altogether 40 kilos" (Nunes, Schliemann & Carraher, 1993).

If a functional solution is applied to solve the problem, then the relationship between the two variables in the given situation is examined and applied to the problem situation.

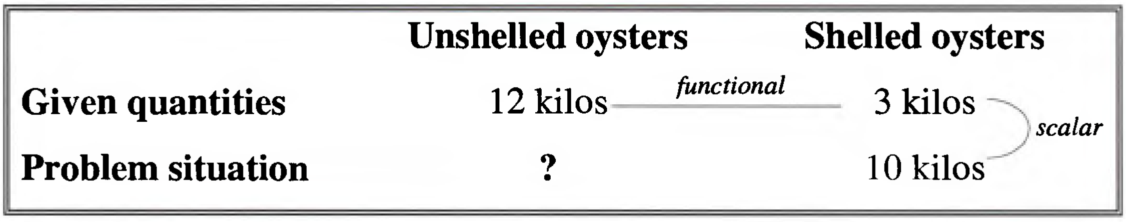


Figure 2.3 Example of a functional problem administered by Nunes *et al.* (1993)

In this case the ratio between the shelled and unshelled oysters is 12 to 4, which can be simplified to 4 kilos of unshelled oysters yield 1 kilo of shelled oysters. If the same relationship is applied to the problem situation, to yield 10 shelled oysters, 10 should be multiplied by 4 giving 40 unshelled oysters.

	Unshelled oysters	**Shelled oysters**
Given quantities	b (12 kilos)	a (3 kilos)
Problem situation	x (?)	c (10 kilos)

Figure 2.4 Example of problem to which the '3 rules' solution can be applied (in Nunes *et al.*, 1993)

The 'three rules' solution was a solution taught in the schools, and therefore a solution that would only be available to the students. It involved converting the information into an equation where 'a' and 'b' are the numbers in the given situation, 'c' is the known number in the problem situation and x is the unknown. The answer is achieved by cross-multiplying the 2 fractions, which can be converted to the equation '$x = (bc) \div a$'. In this case $x = (12 \times 10) \div 3$.

The fishermen showed a high success rate on both types of problems, 83% in the scalar problems and 70% in the functional problems. The students' success rate was not significantly different to the fishermen in the scalar problems. In the functional problems there was a marginal difference between the fishermen and the students, where the fishermen performed better ($\chi^2=1$; d.f.=2.7; $p=.01>.05$). When the strategies for solving the problems were analysed for the fishermen, it became apparent that scalar solutions were being used to solve both the scalar and functional problems. The students' correct solutions for the scalar problems were scalar solutions, and 62.5% of the students' correct solutions for the functional problems were scalar. 37.5% of the correct solutions for functional problems were obtained through either a functional solution or applying the 'rule of three'. The fishermen only applied the functional solution once in the scalar problems and in 12.7% of the functional problems.

This study reveals that if there is a choice between implementing a scalar or a functional procedure to solve a problem, there is a preference for scalar solutions.

Although these problems were presented to older subjects, this preference has also been found with children (e.g. Saxe, 1991). It is thought that this is because the scalar solutions can be obtained by repeated addition. This intuitive solution is one of the first to emerge when reasoning about multiplicative situations begins.

ii. Cartesian product problems

There is another situation that involves the relationship between two sets, which is the Cartesian product problem. It involves the combination of two independent sets to make a new, different set. For example the combination of set 1 (shorts) and set 2 (t-shirts) to make a new set, 3 (outfits). These types of problem are more difficult to solve than co-variation problems.

Bryant, Morgado and Nunes (1992) investigated the solution by 8 and 9 year olds of four multiplication problems, two of which were Cartesian product problems. In one of the problems the children were required to calculate how many outfits could be made with 6 shorts and 4 t-shirts, and they were given objects which represented the t-shirts and shorts. The children were divided into two groups, one group was given all the objects mentioned in the problem and the other group were given a subset of the materials, 2 shorts and 4 t-shirts on which to model their answers. It was hypothesised that the children given the complete set of materials would recreate the situation given in the problem and would be more successful than the group with the subset of materials. It was found that none of the 8-year olds were able to solve the problem without the full set of materials and success with the full set of materials was not significantly better. The 9-year olds were significantly better at solving the problems than the 8-year olds, although these problems were still difficult to solve. When the 9 year olds were given the full set of materials they obtained the correct result about 55% of the time.

The analysis of the strategies and explanations provided by the children revealed that the successful children reasoned about the situation as a one-to-many correspondence situation. One pair of shorts with 6 t-shirts would make 6 outfits, and the number of outfits with 4 shorts, 6 x 4, would make 24 outfits. The results show the impact of the children having materials to represent the problems and support their reasoning, thus showing that, even with these difficult problems, at least some 8- and 9-year old children are capable of solving them using intuitive strategies.

iii. Division, sharing and successive splits

Sharing involves the distribution of a set of among a number of recipients. There are two types of sharing situations, partitive and quotitive. In the partitive division model an object, or a collection of objects is partitioned into a number of equivalent fragments or sub-collections. In the quotitive division model the task is to establish how many times a given quantity is contained in another quantity (Harel, Behr, Post & Lesh, 1994). Although sharing and division appear to be similar, Nunes and Bryant (1996) state that the distinction must be made. Sharing involves a one-to-one correspondence between the shared sets. The child performing the task distributes quantities and makes sure that all the recipients receive the same amount. Division, on the other hand, concerns the relationship between the divisor (amount being divided), the dividend (number into which the divisor is divided) and the quotient (the result of the division). In other words the division operation can be summarised as follows: "dividend ÷ divisor = quotient".

2.4.3.2 Deaf children reasoning about multiplicative concepts

There is little research concerning hearing impaired students and their acquisition of concepts arising from multiplicative situations. Titus (1995) investigated the development of the concept of fractional number in hearing impaired children. There were two groups of hearing impaired children, the younger aged 10 to 12 years and the older, aged 13 to 16 years. They were compared to equivalent aged hearing children and asked to make equivalence judgements about fractions. The study had two parts; in the first the students were asked to make equivalence judgements about pairs of fractions. These fractions were varied, in some the two fractions had the same numerators (e.g. 5/7 and 3/7), in others, fractions with different numerators that were equivalent (e.g. 5/7 and 15/21). In the second part of the study the children were asked to indicate from a different list which of a pair of fractions was larger and indicate their reasoning.

The hearing and deaf students were compared on their success rate and the types of reasoning they gave for choosing their answers. The older hearing children achieved the highest scores with a mean number of correct answers of 11.50 out of fourteen, which was significantly higher than the younger hearing children (7.83) and both groups of deaf children (mean older = 5.75; mean younger = 5.85). All the hearing students outperformed the deaf students. When the performance of the two deaf groups was compared, there was no significant difference between the younger and the older group. When the performance was examined by fraction type the deaf children and the younger hearing children were able to order the fractions with the same denominators, when presented with other types of fractions the children had difficulty with the task. The deaf students (younger and older) displayed a response pattern that was similar to the younger hearing children.

When the reasons given for ordering the fractions were analysed it revealed that the most popular response given by the deaf subjects was described as a 'counting numbers' strategy. Here the students' reasoning focused on the value of the numerator and or the denominator. Ordering of the fractions was based on the value of the counting numbers of which the fraction was composed. For example, when comparing the fractions 8/9 and 24/27 a student wrote 'I know that 24/27 is bigger because it has bigger numbers'. The majority of the younger hearing children's responses were also in this category. The older hearing children did not indicate a use of this strategy, and the strategies they implemented indicated a more mature understanding of fractional order. When discussing the results the author indicated that this study may have included procedures, particularly those which required the students to explain their reasoning, that were too reliant on linguistic ability. Titus also referred to Stone (1991) who theorised that deaf students may have an intuitive understanding of mathematical concepts but may lack the linguistic sophistication to explain their understanding.

This analysis is supported in part by Kidd and Lamb (1993). They investigated whether the linguistic difficulties encountered by hearing impaired students were any different to those difficulties identified in previous research with normally hearing children (Lamb, 1980). The difficulties identified by Lamb (1980) were with words that have more than one meaning, words with special emphasis, technical vocabulary and words with varied forms and symbols.

Nineteen high school children from two classes in an American state school for the deaf took part in Kidd and Lamb's study. The students from one class had an average reading level of around grade 2 and the other class had an average reading level of around grade 5. The age span ranged from 16 to 21 years. During an eighteen-week school term the teachers made anecdotal notes about the difficulties their students encountered.

The majority of difficulties encountered by the students were often related to signing. With the introduction of new terminology that had no sign, the terms often had to be fingerspelled before they could be discussed and taught. Where words have different meanings in a mathematical and everyday context, different signs also often exist for each context (for example 'interest' and 'table'). The students were described as having a false sense of already knowing the word and reverted to using the everyday sign in the mathematical context.

Students were also observed to have difficulties with abbreviation and special symbols such as 'k/h' and '2½'. These abbreviations often occur in co-variation situations where the relationship between the variables has to be decided. These difficulties were resolved by translating 'k/h' to how many kilometres in each hour'. Many students were observed to sign '2½' as 'two and one two' even though they already had demonstrated understanding of the concept of half and knew the correct sign.

These studies indicate that the hearing impaired have difficulties solving tasks which require reasoning about fractions and the formal language which develops from mathematical reasoning. However, this research concentrates on formal aspects of multiplicative situations. There is evidence that young hearing children can reason about multiplicative situations if given access to materials and situations with which they can use their actions (e.g. Harel & Confrey, 1994; Steffe, 1994). This is similar to the research findings in the solution of additive problems. It could be possible that, as with the additive problems, hearing impaired children may also perform better, and display understanding of multiplicative situations, in tasks where they can implement their action schema. The following section describes research with hearing children that has led to a greater understanding of children's reasoning in multiplicative situations.

Some research indicates that multiplicative problems can also be solved initially through actions (Harel & Confrey, 1994). The solutions that rely on actions form the basis of understanding of multiplicative situations. In general it has been observed that these informal strategies rely on a 'heavy use of the situation or context with its concrete and visual supports, rather than depending on symbolic manipulation' (Hiebert & Behr, 1988; p. 9). In contrast, more formal solution methods do not depend on the context but on the manipulation of the abstract or symbolic aspects of the task. The example given by Hiebert and Behr (1988) is one of sharing nine pizzas between 5 children. A child who relies on informal strategies will share out the pizzas to the children repeatedly by, for example, dividing each pizza into fifths and giving each child a fifth of each pizza (resulting in 9 fifths). Alternatively they could give each child a pizza and then share the remaining 4 pizzas between the five children. However, the child relying on formal strategies will decide on the operation 9 ? 5 and solve the problem thus.

2.4.3.3 Hearing children solving multiplicative problems

The following section describes some strategies that have been implemented by young children solving multiplicative problems, which include informal strategies based on the modelling of situations. These strategies have been called 'intuitive strategies' although Vergnaud (1994) prefers to call them 'theorems-in-action' because they demonstrate the use of actions and representations using actions in the solutions of the problems.

Steffe (1994) described a 'pre-multiplying scheme' where a child was asked whether he could calculate how many counters there were when one row of three blocks was visible and five rows of three blocks were not visible. The boy was required to calculate how many blocks there were. The boy solved this problem by counting the three visible blocks using his index finger to point as he counted. He then continued counting in the same fashion, pointing at the empty space, in lines of three for the five remaining rows. Thus he obtained the answer 'eighteen'. Although this child was not multiplying, he still managed to obtain the correct answer. Steffe called this co-ordinating scheme (co-ordinating the concepts of '3' and '6') as an 'enactive concept of multiplication' as opposed to a concept of multiplication as such because there was no indication that the child had made the co-ordination prior to the activity.

A multiplying scheme was also described by Steffe (1994) and involved co-ordinating units. In a situation which explored shapes, the children were shown one shape (red) and then shown 6 equal sized rectangles (blue) that fitted exactly on top of the red shape. The children were then shown some orange squares, two of which fitted exactly onto the blue rectangle. The children were then asked how many orange shapes could fit on the red shape and told to 'figure it out using the blue ones'. The child tapped six fingers in succession and while she tapped each finger she uttered two numbers 'one, two; three, four; five, six; seven, eight; nine, ten; eleven, twelve'. The answer given was that twelve orange shapes could fit on the red one. Steffe referred to this type of counting as an implicit concept of co-ordination. In the action described, the child was assigning two counts (of the orange shape) to one (blue shape).

Lamon (1994) also described an example of an informal strategy, called 'building up'. In the example given the children had been posed the following problem:
Ellen, Jim and Steven bought three helium filled balloons, and paid two dollars for all three. They decided to go back and get enough balloons for everyone in their class. How much did they have to pay for twenty-four balloons?

To solve this problem, the children devised a system that could keep track of the number of balloons being bought (the first number) and the price to pay for those balloons (second number): '3-$2.00; 6-$4.00; 9-$6.00; 12-$8.00; 15-$10.00; 18-$12.00; 21-$14.00; 24-$16.00'. Again there was no formal co-ordination of the two variables and the solution shows similarities with Steffe's (1994) implicit concept of multiplication.

Another form of informal reasoning in a division situation based on action, is the situation where the child shares out a quantity in a partitive situation. Once all the objects to be shared have been distributed one-by-one to all the recipients the child then counts the number of objects each of the recipients have to obtain the solution to the sharing problem. In this situation, the child does not demonstrate a consideration for the two quantities before allocating the items individually. This was highlighted in the earlier explanation as the difference between sharing and division.

The description of these strategies provides an indication of the beginnings of multiplicative reasoning, however, the authors all agree that the children cannot rely on these strategies alone; the children have to go beyond the action schema and reason about the two variables. The evidence reported in the following section demonstrates that although this informal knowledge may be incomplete, it is still powerful enough to allow for reasoning about the relationships between variables in multiplicative problems. This is encouraging for research with hearing impaired children, because if hearing impaired children demonstrate an initial understanding of multiplicative situations through representation, then perhaps they could also demonstrate an understanding of multiplicative relationships. This understanding could form the beginnings of the more formal aspects and language of multiplicative reasoning.

2.4.3.4 Hearing children reasoning about multiplicative situations

Correa (1995) worked with hearing 5, 6 and 7 year olds who showed competence at sharing. The aim of her study was to study children's understanding of division and how this understanding developed. Correa was particularly interested in the children's understanding of the relationship between the three different sets involved in sharing. The three sets are - the total number of objects to be shared (the dividend); the number of recipients (the divisor); and the number of objects given to each recipient (the quota or quotient). In addition, Correa examined the comparative difficulties of quotitive and partitive problems.

Correa (1995) asked the children who took part in her study to solve a series of problems involving distribution of sweets to rabbits where the dividend, divisor and the quotient were systematically varied. In each task there were two groups or parties of rabbits, a party with pink rabbits and a party with blue rabbits, all sharing sweets. The children's task was to make comparisons between the two groups.

In some of Correa's tasks the dividend was kept constant and the number of recipients in each of the groups of rabbits was varied. Here the task was to compare the number of sweets each recipient would receive and in which group the recipients would receive more. These were the partitive tasks. Other tasks involved keeping the dividend constant again, but this time varying the quotient to be given to each group. In these tasks the children were required to compare the number of divisors who could come to each party. These were the quotitive tasks. In other tasks the dividend was different and, again, the quotient of the divisors were varied.

In the partitive tasks the aim was to establish whether children as young as five could understand the inverse relationship between divisors and the resulting quotient. If the dividend was constant, and the number of divisors increased, the amount each recipient would receive (the quotient) would decrease. For example, if six sweets were shared between two people and then a third person came and was included in the sharing situation, the result of the third person joining the sharing situation would be to reduce the number of sweets each person receives. Initially both persons would receive three sweets, with the third person joining they would now receive two sweets each. At the age of seven the majority of the children showed a reasonable understanding of this inverse relationship. However, in this study, it seemed that the understanding of the inverse relationship commenced around the age of six.

When a comparison of partitive tasks and quotitive tasks was made it was found that 5-year olds had greater difficulty solving the quotitive tasks than the partitive tasks. By the age of 6 the success in quotitive tasks had improved but it was still less good than in the partitive tasks. When a task was designed to examine whether the children understood the inverse divisor-quotient relationship in quotitive tasks it was found that, of those 6- and 7-year olds who failed, they did so because they incorrectly applied a direct relation between the number of divisors and the quotient. Ability to judge this inverse relationship seemed to be more difficult in a quotitive context rather than a partitive context.

Desli (1994), working with Greek 6-, 7-, and 8-year olds, gave tasks that were parallel to Correa's with continuous variables. Instead of sharing a number of sweets, she changed the sharing situation to one where the children shared chocolate bars. A comparison between two groups was made and the situations presented to the children were varied. Two groups of children (either the same or differing numbers) shared a number of chocolate bars (again of the same or differing numbers). The task was to assess which of the groups of children would receive more chocolate. Here the children worked with whole numbers and fractions. The older children obtained more correct answers than the younger children. However, a common mistake was to state that the parties with more children would receive more chocolate to eat.

Desli (1994) also found that the distinction between 'within-half' judgements and 'half versus less' than half judgements influenced success in the task. (An example of a 'within half' problem: 'a group of four children sharing 3 chocolate bars compared to a group of eight children sharing 6 chocolate bars'. An example of a 'half versus less than half' problem: 'a group of four children sharing 2 chocolate bars compared to a group of eight children sharing 3 chocolate bars'.) All the children performed at ceiling level when the half-boundary could be used as a reference for their judgements. Desli also examined the variation between one-variable and two-variable problems. One-variable problems (where either the children or the chocolates were different in both groups) were compared to two-variable problems (where the numbers of children and chocolates were different in both groups). The two variable problems were more difficult as a group, but those involving the half boundary were not more difficult than the one-variable problems.

Both the Correa and Desli studies indicate that children who have not previously encountered multiplicative situations at school are able to demonstrate an understanding about multiplicative situations previously thought to be too difficult for them. As found in the research concerned with additive problems, reasoning about multiplicative situations is initially achieved through using informal strategies. Moreover, these strategies are based on action and are thought to form the base of more mature forms of multiplicative reasoning (Kieran, 1994). Kieran (1994) stated that action schema did not lead to a complete mature scheme of multiplication in and of itself, but added that such a simple action scheme could also underlie the solution to simple proportion and simple linear function problems.

2.4.3.5 Hearing impaired children reasoning about multiplicative situations

A series of multiplicative problems were presented to hearing impaired children in school years 2 through to 5 attending special schools and units for hearing impaired children around London by Nunes and Moreno (1998b). The problems presented included sharing with continuous and discontinuous variables similar to those presented by Desli (1994) and Correa (1995). One purpose of administering these problems was to assess whether hearing impaired children also used action schemas to solve multiplicative problems. The same problems were administered twice, once with cut-out objects representing the items in the problems, and again with materials that were normally available to the children in the mathematics classroom such as unifix, Dienes blocks and number lines. It was hypothesised that the children would obtain a significantly higher number of problems correct when they had access to the cut-out objects. This was because the objects would encourage the children to represent and keep track of the problem. The hypothesis was supported, out of nineteen problems that involved calculation the children obtained a mean of 10.3 problems correct with the cut-outs and 8.8 with the mediators from the classroom. A mixed analysis of variance with year group as the between groups factor and condition of testing as the within subjects variable and the number of correct answers as the dependent variable was carried out. There was a significant effect of condition ($F = 8.54$; $p = .006$), a significant effect of year group but no significant interaction. The children in all the year groups performed significantly better when solving the problems with cut-out objects. Here the children used their action schemas to represent the problems and the objects helped them keep a sense of the problem. When solving the tasks using blocks and number lines some children would lose track of the problem, forgetting for example which blocks represented the divisor and which the quotient.

When these results are compared to the difficulties that hearing impaired children encounter with the more formal aspects of multiplicative reasoning described by Titus (1995) and Kidd and Lamb (1993). It suggests that hearing impaired do understand the informal aspects of multiplicative situations. The children in the Nunes and Moreno (1998) study were able to demonstrate understanding of multiplicative concepts when representation of the problems was facilitated by the use of cut-out materials. However, the transition to the more formal aspects of multiplication, division and fractions is not made easily by this group of children. Indeed the same multiplicative problems are significantly more difficult to solve if administered with more formal or abstract materials. This is similar to the findings reported above with hearing children, suggesting similarities in development between the deaf and hearing children.

2.4.3.6 Summary

This chapter has examined the possible areas of difficulty in the acquisition of mathematical concepts for hearing impaired children. Firstly, the acquisition and development of numbers could take longer for hearing impaired children to master in comparison with their hearing peers. Secondly, examination of the solution of additive problems indicates that hearing impaired children, like hearing children, use action schema to reach a solution. There is also reason to believe that they could implement these action schemas when solving multiplicative problems. However, there seems to be evidence that there could be difficulties moving on from these informal strategies to the more formalised aspects of mathematics which are taught and assessed in school.

The transition from the informal to the formal strategies is important in the understanding of mathematics, because a reliance on the action schema would lead to incomplete knowledge of mathematical concepts. This transition is not an easy one for hearing children to make. An examination of research with hearing children exploring the ways connections between the formal and informal reasoning strategies are made could give indications as to how these connections are made with hearing impaired children.

Research with hearing children has indicated that the connections are made through instruction, more often than not in the classroom. Researcher have argued that the role of language and the way problems are presented has been seen to be critical in the acquisition of the formal concepts (e.g. Kieran, 1994). As was mentioned previously, the linguistic abilities of the hearing impaired vary greatly. Communication is a particular area many of these children may find difficult to overcome. The transition towards the formal seems to rely, at least in part, on the communication process that goes on particularly in the classroom. On this basis, there is reason to believe that addressing the communication needs of hearing impaired children adequately could give a more facilitated access to the formal language and aspects of mathematics education. However, this has not been investigated. It has been established that deaf children do use informal strategies, based mainly on their action schema, for the solution of additive and multiplicative problems (Nunes & Moreno, 1998). It has already been established that they have difficulties with the more formal language associated with more advanced mathematical problems (Kidd & Lamb, 1993). ...

2.5 The present study

2.5.1 Establishing criteria for study

The aim of the present study is to identify skills and variables that predict mathematical competence in hearing impaired children. The literature described in the present chapter suggests that the numeracy development of hearing impaired children follows the same developmental path as hearing children. However, the hearing impaired children may experience difficulties acquiring certain skills, such as counting, causing a delay in general numerical development. If this is so, it is should be possible to identify predictors of mathematical attainment in hearing impaired children. If hearing impaired children demonstrate a delay in skills that predict mathematics then this must explain the cause of lower achievement that many hearing impaired children demonstrate.

In order to identify these explanatory predictors they must satisfy two criteria: The hearing impaired children must demonstrate a delay on the explanatory tasks in comparison to hearing children; and these measures must also predict mathematics scores in a longitudinal study. Two studies were carried out to investigate whether the range of predictor variables could satisfy these criteria. The first study administered a range of cognitive, linguistic and numerical tasks to hearing impaired children and compared their performance either directly with hearing children or with standardised norms based on hearing populations. In this comparative study the aim was to identify whether the hearing impaired children were behind their hearing peers on any of these measures. In the second study, the relationships between the various predictor measures and mathematics scores obtained over a school year were explored. The aim of this study was to establish which of the tasks were successful at predicting mathematics scores. Only those tasks on which the hearing impaired performed below their hearing peers and that explained a significant amount of the attainment of mathematics can be considered as causal explanations for the lower achievement in mathematics. The following section describes the tasks included as predictors in this thesis.

2.5.2 Predictor tasks

2.5.2.1 Demographic variables

It was necessary to collect demographic information including audiological information. Previous researchers found weak associations between mathematics attainment and these demographic variables.

2.5.2.2 Linguistic ability

Marschark (1993) stated that that range of linguistic ability in the hearing impaired is vast. Hearing impairment has an impact on linguistic development. It may be that the linguistic delay experienced impacts further learning throughout the school curriculum. A measure of linguistic ability was included in the study and the relationship with mathematics was explored.

2.5.2.3 Number processing skills

Hitch *et al.* (1983) and Epstein *et al.* (1990) found that the number processing skills were slower in hearing impaired participants than hearing participants. The assumption was made that this could explain lower mathematical attainment in hearing impaired children. This is tested directly in the present thesis, for number processing skills to be a predictor of mathematics, the hearing impaired must be slower that the hearing children and the task must be significantly associated with mathematics scores.

2.5.2.4 Early numerical ability

The literature suggests that hearing impaired children may experience a delay in acquiring early numerical skills such as counting ability and the understanding of the additive composition of number. The Shop Task, which assesses the additive composition of number, in particular is a predictor of mathematics in hearing children (Nunes, Silva & Miranda, 1991). Nunes and Moreno (1998b) found that the Shop Task is also a predictor of score on a standardised mathematics assessment with hearing impaired children. The present study includes counting ability and the Shop Task as possible predictors of mathematical attainment.

2.5.2.5 Concepts about time

In Nunes and Moreno (1998b) a range of additive word problems were administered to a group of hearing impaired children. During the administration of these word problems a number of issues about the nature of word problems arose. It was noted that the inverse problems where the 'change' or 'start' amount was unknown were particularly difficult. Analysis of these word problems revealed that the task requires a number of operations for its successful completion. Firstly, the computation using the numbers must be carried out. However, three additional features of the word problems were noted that have to successfully manipulated if the computation is to be successful. The child has to be able to reason about change in situations. Will the amount increase or decrease if the boy gives his flowers? An additional feature is that the child has to deal with a sequence of three units of information, one of which has to be calculated or inferred. The order of this sequence must be maintained even if the amount of the first and second units is not specified, as is the case in 'start unknown' and 'change unknown' additive word problems. Lastly, another task requirement is to invert the order of information that is given. A word problem with 'start unknown', for example, requires that the child work backwards from the final amount and the transformation to the initial state. These features all deal with time, a concept that has been noted as difficult for hearing impaired children to master. Gregory (1995), for example, reported anecdotes from mothers about the difficulties they experience when talking to their hearing impaired children about time. Some mothers noted that talking about the past was difficult, for example: "You can't really talk a lot about things that she did because she thinks that you're saying that she's going to do them again ... (p. 5). Other mothers made observations about difficulties when talking about events in the future, "You can't say, like when we go to Robert's to play, 'We're going now, we'll come back tomorrow. Just one more day and we'll come back' ... to him we're going and we're never going there again as far as he's concerned. You know you can't explain that you will go back again ... (p. 4)" Previous research has also noted that hearing impaired children may have difficulties recalling information that is presented in a sequential order (Marschark *et al.*, 1993). A task that assessed these requirements in a non-numerical context was desired. If these concepts are difficult for hearing impaired children to deal with then this may explain difficulties in mathematics generally.

Research has investigated the ability to invert the order of events with hearing children by exploring the comprehension of phrases with the words 'before' and 'after' in the description of a sequence of events (e.g. Johnson, 1975; Trosberg, 1982). Examples of the types of phrases used these studies were:

1. The boy patted the dog before he kicked the rock.
2. After the boy patted the dog, he kicked the rock.
3. Before the boy kicked the rock, he patted the dog.
4. The boy kicked the rock after he patted the dog.

These types of phrases, all including the words 'before' and 'after' were presented to children aged 3 to 5 years. The children were required to act out the events in the correct order using toys. It was hypothesised that those phrases where the order of mention of the events coincided with the order of occurrence (for example sentence 1) would be the easiest for the children to act. This was found to be the case. The older children taking part in the study (5-year olds) were able to pay attention to conjunctions used in the phrases. Most of them understood the order of events for all four types of sentences (in Clark and Clark, 1977).

The results in this task suggest that there is a development in the understanding of these types of clauses. One would expect hearing impaired children, most of whom experience a general linguistic delay, to have difficulty with these types of phrases also. If these same phrases and ideas are presented in additive word problems, these may lead to difficulties or confusion regarding the order of events and consequently the computation. An assessment of hearing impaired children's ability to deal with sequential information and that deals with time and change was required to test this hypothesis.

The phrases used in the study described previously by Clark and Clark (1977) were not appropriate for use with hearing impaired children. A number of these children either sign or have some reliance of sign at school. The sign for 'after' could be confused with the sign for 'next'. A sentence such as: 'The boy kicked the rock after he patted the dog' could be interpreted as a list of events. '(The) boy kicked (the) rock, next, (he) patted (the) dog' (words in brackets are not signed). In BSL there is a tendency to rearrange the order of events so that they are presented in the correct chronological order. Alternative tasks that assessed hearing impaired children's ability to sequence temporal information had to be devised. Three different tasks were designed and will be used in the present study. Each task covered a different aspect of the linguistic structures found in additive word problems. The first described a situation of change; the second described two distinct events occurring on different occasions and the third involved reasoning about three information units presented in a sequence.

2.5.3 Study designs

2.5.3.1 Comparison study

The design of the study is summarised in table 2.4. All of the tasks mentioned were administered to the hearing impaired children taking part in the study. Direct comparisons of their performance were made with hearing children on a mathematical assessment, the time concepts, the memory scan task and the Shop Task. Comparisons with standardised norms were made with other mathematical assessments and linguistic assessments.

Table 2.4 Summary of the design of the Comparison Study

Task	Compared to hearing children	Compared to norms
Mathematics assessments	✓	✓
Language assessments		✓
Number processing skills	✓	
Time concept task	✓	
Early numerical ability	✓	

2.5.3.2 Predictive Study

Only the hearing impaired children took part in the predictive study. They were tested on three occasions: time 1, time 2 and time 3. The design for the predictive study is summarised in table 2.5. The outcome measure for the study was mathematics score and these were assessed on all three occasions. All the predictive measures were administered at time 1. Another predictive measure, the receptive language task was administered at time 3 because a floor effect was obtained for the language assessment administered at time 1.

Table 2.5 Summary of the design for the Predictive Study

Time 1	**Time 2**	**Time 3**
Mathematics assessment	Mathematics assessment	Mathematics assessment
Language assessment		Language assessment
Demographic information		
Non-verbal IQ		
Number processing skills		
Time concepts		
Early numerical ability		

3 Comparison study

3.1 Chapter organisation

The purpose of the chapter is to examine the first criterion set for the study, that is to establish whether the hearing impaired children were behind hearing children on a range of cognitive and linguistic tasks. Only if the hearing impaired children were behind on these measures, could they be included as predictors of mathematics attainment in the following chapter. The hearing impaired children were administered a range of assessments and their performance was either compared directly with hearing children or with published norms based on hearing populations. In this way it is possible to establish whether hearing impaired children demonstrate a delay in cognitive assessments in comparison to hearing children. For ease of reading, during the description of the procedure, the tasks administered to compare directly with the hearing children are described first. Tasks where the hearing impaired children's performance is compared to published norms are described in the following section.

3.2 Method

3.2.1 Subjects

3.2.1.1 Hearing impaired children

42 hearing impaired children took part in the present study aged between 7 years and 2 months and 9 years 1 months ($\bar{x}$=97.24 months) during the Autumn term of 1997. The children attended schools and units for hearing impaired children located in seven different sites around London. There were 22 children in Year 3 and 20 children in Year 4. There were 19 girls and 23 boys. The children in the present study had hearing losses ranging from mild to profound, the exact number of children is shown in table 3.1. As can be seen in table 3.2, the cause of hearing loss was known for 22 children, 20 children (47.60%) had unknown causes of hearing loss.

Table 3.1 Number of children by degree of hearing loss

Degree of hearing loss	Number of children
Mild to moderate	5
Moderate to severe	9
Severe	14
Profound	14

Table 3.2 Number of children by cause of hearing loss

Cause of hearing loss	Number of children
No known cause	20
Hereditary	10
Difficulties at birth (e.g. premature)	5
Meningitis	4
Associated with chromosomal abnormality	2
Rubella	1

The researcher contacted a number of schools around London requesting permission to work with hearing impaired children in Years 3 and 4. The researcher visited those schools who had responded positively to the request. Once at these schools, the parents of the eligible children were contacted and their permission for the child's inclusion in the study was requested. Only those children whose parents had given permission were included in the study. 47 children were approached and all took part in at least one testing session. If it was seen that the child could not take any further part in the study then testing was discontinued and they were excluded from any further sessions and future analysis. Four children were unable to take further part in the study. All four of these children were unable to follow the researcher's instructions and three of these children were unable to identify written numbers. These children were confirmed by the teachers as requiring additional educational support for reasons other than their hearing impairment. The remaining 43 children were administered all the assessments and tasks. However, one child was excluded from the analysis because she had Down's syndrome in addition to her hearing impairment. The child's scores on the assessments were very low and it was possible that these reflected difficulties arising from the Down's syndrome rather than the hearing impairment specifically. For the rest of the analysis, only the 42 hearing impaired children who received the whole battery of tests and who were included in the analysis will be referred to.

3.2.1.2 Hearing children

69 hearing children, 33 boys and 36 girls, classmates of children attending a hearing impaired unit (HIU) based in a mainstream school participated in the study. The children were aged between 7 years 2 months to 8 years 11 months ($\bar{x}$ 98.16 months). There were 35 children in Year 3 and 34 children in Year 4. The proportion of boys was slightly larger in the hearing impaired sample. However the sample was not significantly different in age so it was considered an adequate match for the hearing impaired sample. Some of the children (37 children, 13 in Year 3 and 24 in Year 4) were administered the mathematics assessments, the memory task and the tasks assessing mental operations involving time. The remaining children were only administered the Shop Task.

3.2.2 Instruments administered for direct comparison

3.2.2.1 NFER –Nelson Graded Arithmetic tests

There are no mathematics assessments standardised for a population of hearing impaired children, so two assessments standardised on a population of normally hearing children were used in this study. The two tests were chosen because they rely less on verbal instructions than other assessments by presenting most of the material visually.

First, the appropriate forms of the NFER-Nelson 7-11 mathematics series were administered. The test designed for 8-year olds was administered to children in year 3 and the test designed for 9-year olds was administered to the children in year 4. The range of problems included in the assessment ranged from computation, recognising shapes and solving problems with money and weights.

Procedure

The hearing impaired children were administered the test individually by a signing hearing impaired researcher, familiar with SSE and at stage 2 level of signing in BSL. The children in the final sample varied in their need for signing to support their communication. The schools differed in their language policies, but were similar in their flexibility when using sign to support communication. If it was felt that a child required sign as an additional support to communication, then it was provided. The extent to which sign was provided depended on the apparent needs of the individual child. As a consequence of this need to take this into consideration, the researcher read each item to the children in the communication mode appropriate to the child.

The hearing children took the test as a class. The class teacher administered the test with the researcher observing and assisting with the administration. The 'Mathematics 8' test was read out by the class teacher, following the published administration procedures. The children responded to each question in the test in turn. The test designed for the 9-year-olds (the 'Mathematics 9' test) was not designed to be read out for the whole class. The children had to read the instructions themselves and work at their own pace. The children worked alone but if they required any clarification of any words or instructions used in the test, they were allowed to ask the teacher or the researcher. Any explanations offered were within the assistance permitted in the published manual.

The tests were originally designed as a group test for hearing children so the published procedure was followed. However, the hearing impaired children were assessed individually for two reasons. Some of the hearing impaired children were the only hearing impaired child in their year group, in these cases the assessments had to be administered individually. Similar conditions for all the hearing impaired children was desirable so all the children were assessed individually. It was also felt that administration tailored for the individual child's communication needs would encourage the best performance from each child.

The tests were marked according to the published instructions and the standardised scores were calculated by taking the child's age at the time of testing into account.

The published procedures were followed to obtain these scores. There were cases where the child's raw score was too low to be standardised. The publisher was contacted and information about the standardised scores for these children was requested. However, this information was not available because too few hearing children in the norm sample had obtained these low results. To avoid having too much missing data, and for the purposes of analysis alone, the low raw scores were given a hypothetical standardised score. Those with a raw score of 5 were given a 'standardised score' of 69, that is one point below the lowest standardised score. Those with a raw score of 4 were given a 'standardised score' of 68. Those obtaining a raw score of 3 were given a 'standardised score' of 67. Those obtaining a raw score of 2 were given a 'standardised score' of 66 and those with a raw score of 1 were given a 'standardised score' of 65.

3.2.2.2 Memory scan task

An adaptation of the memory scan test by Sternberg (1975) was administered to the children taking part in this study. This specific memory span task was chosen because it had been used in a previous study with hearing impaired students (Epstein *et al.*, 1990), and because the task is very visual.

Procedure

The task required the subjects to assess whether a probe digit had been present in a previously displayed stimulus set. The children were told that they were going to play a game about remembering numbers. They were told that they were going to see some numbers on the computer screen that they had to read and remember. They were then told that this number would then go away and one number would appear. Their task was to decide whether they had seen this latter number in the previous set of numbers.

In the study by Epstein *et al.* (1990) there were 120 trials but this was reduced to 60 trials because it was felt that the original task was too long for 8- and 9-year old children. In each trial the subject was presented a series of images on a computer screen. They were presented firstly with a fixation point (a cross) for 1 second on a screen (screen 1 in figure 3.1). The participants were then presented with a blank screen for 500 milliseconds. The stimulus set was then presented for 4 seconds (screen 2 in figure 3.1). This was longer than the 1-second presentation in the Epstein *et al.* (1990) study. It was felt that some children could be slower readers; presenting trials at a speed that was too quick for them to read the numbers would place them at a disadvantage and discourage them early on in the task. Next, a blank screen was presented again for 500 milliseconds. Lastly the probe digit was presented on the screen and remained there until the subject responded (screen 3 in figure 3.1). The children were then asked: ‘Did you see the number by itself in the group of numbers you saw before? If you think ‘yes’ then press the ‘✓ ’, if you think ‘no’ then press the ‘✗ ‘ button.’ The ‘z’ and ‘/’ keys had stickers placed on them to help the children remember which keys to press. As well as this, on the corresponding sides, stickers were placed next to the screen. A sticker with the word ‘no’ was placed to the right of the screen and a sticker with the word ‘yes’ was on the left-hand side of the screen. The question was asked during the practice trials, but during the testing session the children were required to respond immediately without being asked the question. There was no time limit for response but the response time was recorded. Following the participant’s response there was a 500-millisecond delay before the next trial.

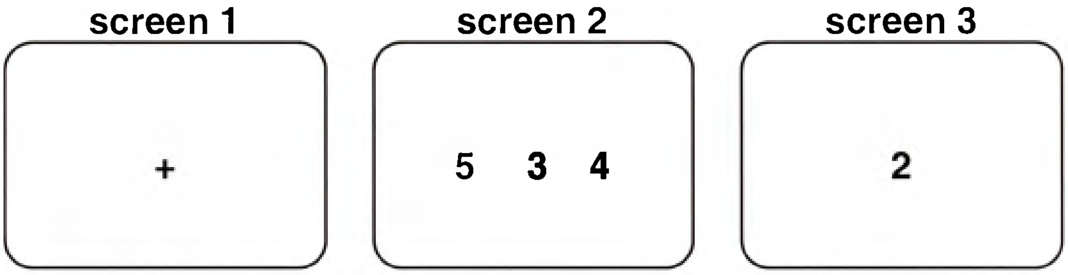


Figure 3.1 Example of a memory scan trial with a stimulus set size of 3 digits and a negative probe

There were six stimulus sets ranging from 1 to 6 digits and there were 20 trials for each stimulus set size. Half the trials within each stimulus set size were positive (the probe digit was present in the stimulus set) and the other half were negative (the probe was not present in the stimulus set). The numbers between 1 and 9 were evenly distributed within stimulus sets and positive and negative probes. The position of positive probe also evenly distributed in each of the stimulus sets. The children were given practice trials with stimulus sets of two digits to ensure that they had understood the instructions. If it became apparent that the child did not understand the instructions then they were explained again using the trial as an example. The instructions were rephrased until the child had understood the task requirements. There was no fixed number of practice trials since the emphasis was on comprehension of the instructions. The practice trials were not included in the testing session.

Information about each trial was collected. For the stimulus sets - the digits and the length were recorded. Information about the probe included whether it was a negative or positive probe and the actual digit shown. For each trial the responses were recorded, their accuracy and the response time to one hundredth of a second. Rest periods were provided after the 15th, 30th and the 45th trials.

3.2.2.3 Mental operations involving time concepts

A series of tasks was designed to assess the ability to reason about time concepts. The tasks were designed to assess reasoning about these concepts in a non-numerical context to establish whether the hearing impaired have particular difficulties with operations on time independently of their having a numerical context. Three tasks were designed: the first assessed the ability to identify a picture on the basis of incomplete sequential information; the second assessed ability to invert the order of two events; and the third assessed ability to reason about situations involving a change.

Procedure

All the questions in the different tasks were administered together, in a random order, over three or four different sessions. Altogether there were sixty-four different questions. The format for all the questions was very similar. In each case the child was presented with a choice of drawings, the child had to point to the drawing seen to be the correct answer. The drawings were presented to minimise the reliance on memory and to support the communication of the story. The pictures also a useful tool because pointing could be the mode of response.

Previous to the administration of these questions, three preliminary questions were asked. The children were shown three different pictures, one of a boy holding some balloons, another of a jar of sweets and another of some toys. The children were asked if the boy in the picture would have more, less or the same number of balloons if Daddy gave the boy some balloons. The children were then asked if the jar in the picture would have more, less or the same number of sweets if they ate some of the sweets. They were also asked if they would have more, less or the same number of toys if they lost some of the toys in the picture. The aim of administering the questions was to establish whether the child understood the transformations that occur if one loses or gains objects. If the child did not demonstrate understanding, then the situation was discussed further. The transformation was demonstrated using objects until the child indicated understanding for the transformations. This was to ensure that they would understand the picture questions when they were presented. The following sections describe the development and the administration of the stimuli presented to the children. Each task is presented separately. A full script and all items are included in Appendix A together with an example of the protocol for recording the children's responses. The tasks were presented in the child's preferred mode of communication, oral or sign. If the instructions were signed, they were presented in Signed English with the use of placement to minimise confusion.

a. Identification of a picture sequence from sequential information

The present task was concerned with three elements of information presented in sequence. The aim of the task was to assess whether the child could identify a drawn sequence that corresponded to the instructions given to the child in a story format. There were two types of items, the control items and the experimental items. The location of the correct response was randomised throughout each trial.

The purpose of designing control items was to ensure that the children had understood the instructions of the task. They had the same structure as the experimental items but differed only on the lack of inference required to correctly solve the task. The structure of the two types of items were identical in the length of the stories, thus keeping the memory load constant, and in the words used such as the expression 'don't know', thus keeping the linguistic content constant. Any differences between the types of items can be assumed to be as a result of the need to keep in mind that there was a gap in the story sequence and hold a position empty with a 'place-holder'.

i. Control items - no place-holders required

There were two types of control items. In the first, all the elements in the sequence were mentioned. On the basis of this, the child had to identify which of the four pictures matched the story. For example: 'There were three cars waiting at the traffic lights, the first car was red, the next was blue and the next was orange.' No inference was required to identify the correct picture. The mental representation for this story is shown in figure 3.2.

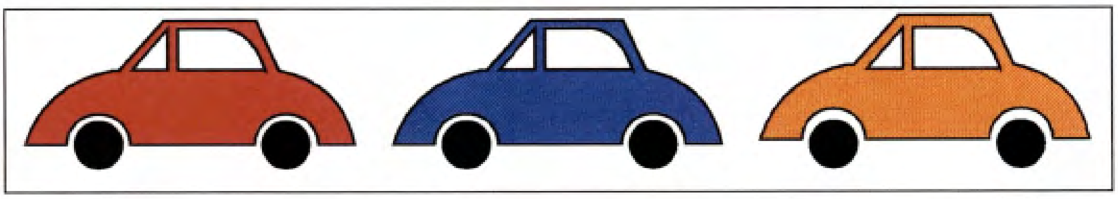


Figure 3.2 Mental representation of 'all elements mentioned' item

The second type of control item was designed to control for the use of a place-holder, the 'don't know' sentence in the experimental item. In the 'third not mentioned' item the third object in the sequence was not specified.

For example: 'There were three cars waiting at the traffic lights, the first car was red, the next was blue and I don't know what colour the next car was.' In this case inference was also not necessary because the child could match the first two objects to obtain the correct answer. Figure 3.3 shows the mental representation required for this type of question.

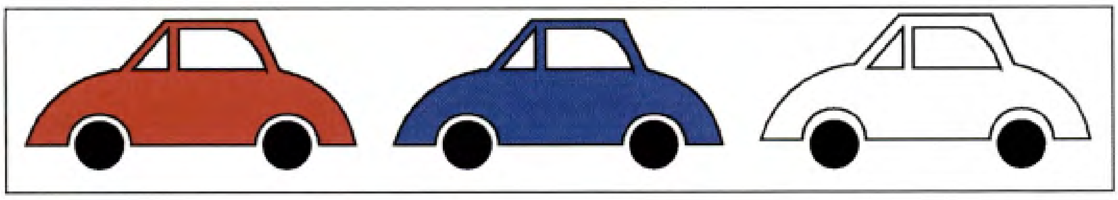


Figure 3.3 Mental representation for 'third element not mentioned' item

ii. Experimental items - place-holders required

The information given these in these stories was incomplete, either the first or the second element of information was missing. To obtain the correct response, the children needed to keep in mind that there was a gap in a particular place in the story, hold the position empty with a 'place-holder' while identifying the other objects mentioned in the sequence.

In the 'first element not mentioned' item the first element in the sequence was not specified, so the first space required a place-holder.

For example: 'There was some cars waiting. The first car, I don't know what colour it was. The next car was blue and the next car was orange'.

As shown in figure 3.4, the correct mental representation leaves a place-holder, in this case a car of unknown colour in the first space and then the blue and orange coloured cars in the second and third spaces.

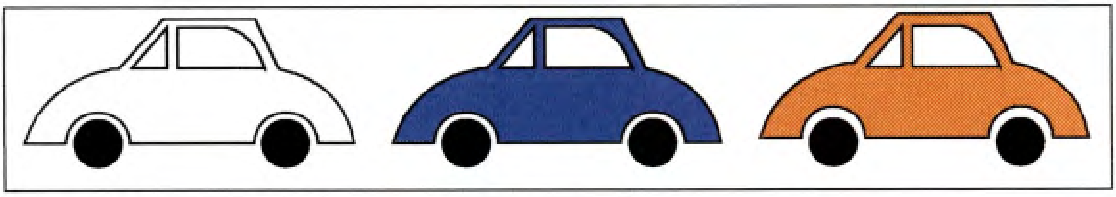


Figure 3.4 Mental representation of 'first element not mentioned' item

In the 'second element not mentioned' items, the second element in the sequence was not specified, so the second position required the place-holder.

For example: 'There were three cars waiting at the traffic lights, the first car was red, I don't know what colour the next car was and the next car was orange.'

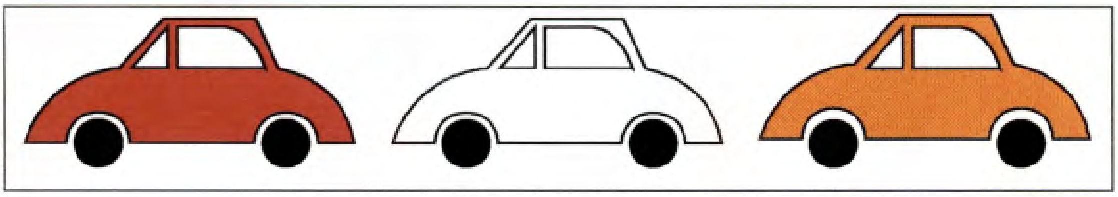


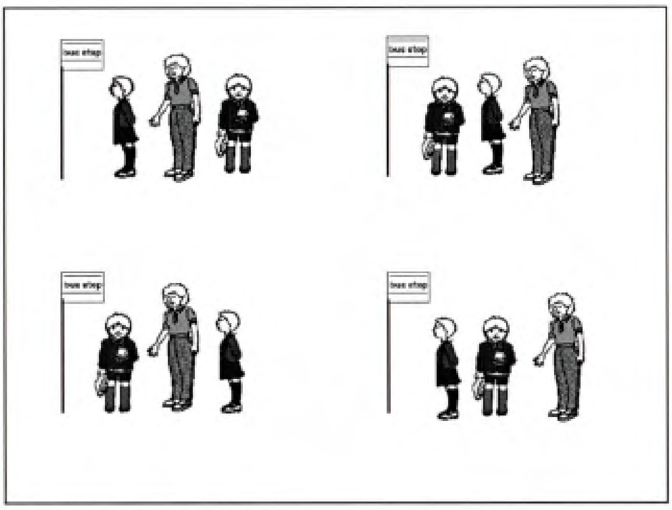
Figure 3.5 Mental representation of 'second element not mentioned' item

As shown in figure 3.5, the correct mental representation in this case has to place a red car in the first position, a car of unknown colour in the second space and then an orange car in the third position.

In the task itself, the child was shown a card with four different pictures. The stories told referred to different situations: a queue at a bus stop; a tower of three building blocks; a toy caterpillar; a toy train; traffic waiting at the traffic lights; and beads on a knotted string. The pictures were discussed the first time they were shown. For example, in the picture shown in figure 3.6, each bus queue was discussed in turn. A question was asked about who was first in the queue, or who would get on the bus first when it arrived. The aim of asking these questions was to ensure that the child had paid attention and understood the picture.

Having ensured that the child had understood the pictures, the questions were then asked. The child was told that they had to look for the picture that matched (or 'is the same as') the story that the experimenter told.

Figure 3.6 shows an example of a 'first element not mentioned' question administered to the children in the study. In each case the information was presented as a sequence of: 'a', next 'b', next 'c'.



"There were three people waiting for the bus.
The first person waiting for the bus, I don't know who it was...
The next person was a girl and the next person was a lady.
Which picture shows the right bus stop?"

Figure 3.6 Example of a 'first element not mentioned' question

The child was allowed to look at the pictures while the story was being told and one repetition of the story was allowed. If the hearing impaired child looked away at any stage of the story, the researcher waited until eye-contact was resumed to continue with the instructions. After hearing the story, the child has to point to the picture that matched it. The child was not required to repeat the story but most of the children did this spontaneously.

b. Inversion of surface structure of events

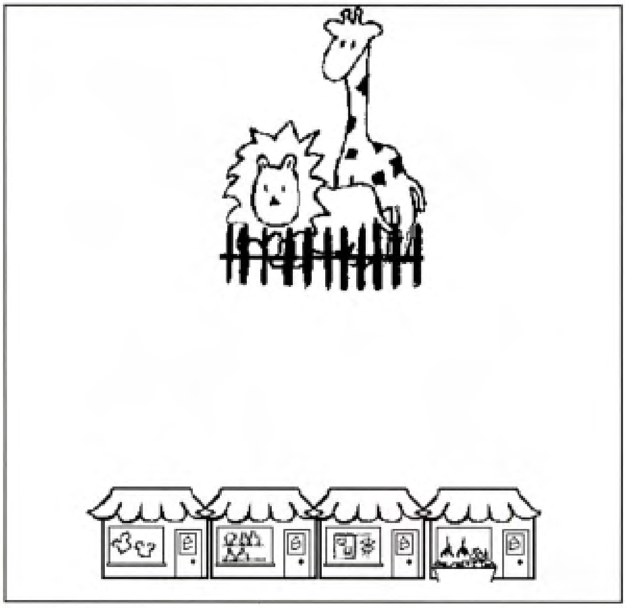
The children were told a story where two events happened, one before the other. The events were marked with a day reference, the words 'today' and 'yesterday'. Day references were used instead of the traditional 'before' and 'after' instruction because of the possible confusion with the sign 'next'. The aim of these tasks was to examine whether the child could invert the order of the events presented in the story. In this task there were two types of items, the experimental and control. In both items the story was told and questions were asked in the order they were mentioned in the question (see figure 3.7). The aim of asking these questions was to ensure that the child had remembered the story correctly. If the child answered incorrectly on these questions, they were corrected and the question continued. In the event of this occurring, it was noted on their answer sheet.

i. Control items - No inversion required

The events that occurred in the story were told in the order that they occurred, 'yesterday x happened and today y happened'. This was to ensure that the children had understood the instructions and the vocabulary used in the stories. Each story was told with the support of two drawings depicting each event to minimise the reliance memory and communication problems. The child's task was to identify, using the drawings, which event occurred first.

ii. Experimental items - Inversion required

The events occurring in the story were not told in the correct chronological order. Each story in the experimental items had the following structure: 'today x happened and yesterday y happened'. The story was told with the support of a drawing depicting each event to minimise the reliance memory and communication problems. The child's task was to identify, using drawings, which event occurred first.



"Yesterday I went to the zoo.
Today I went to the shops.
Where did I go yesterday? (child points)
Where did I go today? (child points)
Where did I go first? (child points)"

Figure 3.7 Example of an order of events question requiring no inversion

c. Inferring time sequences from change

These tasks told a story where two events occurred to the same person. The task was to identify the picture that represents the initial state before the transformation. The structure of all these questions was to describe a situation in which an action takes place. The specific aim of these questions was to examine whether the child could infer order in time from states before and after a change. Each story was told and then the child was asked to repeat the story without looking at the pictures. If this was difficult, the experimenter gave prompts to aid recall. The child was asked: 'who is in the story?'; 'What did he have?' and 'Then what happened?' The child was then asked to point at the picture showing the initial state indicated in the story (see figure 3.8). Other children did not require prompts when asked to recall the story. Many children repeated the story almost exactly, other children added reasons for the events occurring and added to the story.

In each item the two drawings differed only in the number of objects. Inference about the story had to be based on the number of objects, and not on external cues such as facial expressions of the characters involved in the story. There were two items. In this way it was possible to control for responses driven by strategies that involved pointing to the largest or smallest quantities only.

i. Change increase

The story involved the person in the story gaining more items. The task was to identify which picture shows the beginning of the story.

ii. Change decrease

The story involved the person in the story losing or giving items. The task was to identify which picture shows the beginning of the story.

"The boy had some toys. Then daddy gave him some toys."
(Child repeats the story without looking at the picture)
Which picture shows the beginning of the story?

Figure 3.8 Example of inference about time sequences from change question – change increase

3.2.2.4 Knowledge of the Additive Composition of number

Knowledge of the additive composition of number was assessed by Nunes *et al.* (1991) using the Shop Task. The same study found that the Shop Task was related to formal mathematical assessments in hearing children. Nunes and Moreno (1998b) also found the Shop Task to be predictive of mathematical ability in hearing impaired children. No direct comparisons have been made between these two groups of children. The present study makes this direct comparison.

Procedure

The children were told that they were going to play a shop game. They were allowed to choose which items they could buy from the shop and then they were told the price. The child was given different coloured counters to represent different values of coins. The child had to pay for the items by combining the values of the different counters. They were given one 5p counter and four 1p counters. The values they were asked to give were 5p, 7p and 9p in a random order. The child was then given five 10p counters and nine 1p counters. The child was asked to pay the values of 13p, 17p, 20p, 21p, 23p and 30p. These were also presented in a random order.

3.2.3 Tasks administered only to the hearing impaired children

3.2.3.1 WISC-III UK Performance Scale

The performance scale of the WISC-III was administered to provide a general measure of cognitive ability in the present sample. Studies of intelligence in hearing impaired subjects have shown that the non-verbal (or the 'performance') scale of intelligence tests are more appropriate for this population group. The WISC-III manual (Wechsler, 1992) reports the administration of the Wechsler Intelligence Scale to a sample of hearing impaired children in the United States. The administration procedures were adapted by implementing the American Sign Language or Pidgin Signed English, depending on the communication needs of the child. The mean scores were calculated for each scale. The Verbal IQ, Performance IQ, Verbal Comprehension Index score, Perceptual Organisation Index score, the

Processing Speed Index score and the Freedom from Distractibility score were calculated. The sample scored lower in the verbal IQ and the Verbal Comprehension Index, as was expected. The manual also notes that special caution must be taken when interpreting the scores of any special population, particularly when the administration has to be adapted (Wechsler, 1992; p.106). It was thought appropriate to administer this test to the present population, bearing these caveats in mind.

Procedure

Following the published procedure four sub-tests of the Performance scale were administered in the communication mode most appropriate for the child, either signed supported or oral English (Wechsler, 1992). The sub-tests were 'Picture completion'; 'Block Design'; 'Object Assembly' and 'Coding'. A total was obtained from the scaled scores from each sub-test. A pro-rata total was calculated and from this an estimated IQ was obtained.

3.2.3.2 Reading Comprehension Task

A measure of linguistic ability was required that met certain requisites. The measure had to be such that it could be administered regardless of the mode of communication so that all the hearing impaired children taking part in the study could be assessed fairly. It also had to cover a wide range of linguistic ability. The present sample included children who were very able linguistically but the majority of the children were behind in their reading and linguistic skills.

On the basis of these requisites, the Individual Reading Analysis (1990, formerly known as the MacMillan Individual Reading Analysis (MIRA)) was chosen. The MIRA has a measure of reading accuracy and reading comprehension. This task was used because it is targeted for those children who are expected to show a more restricted and lower ability range in reading. It has been used, for example, in clinics and studies focusing on children with language impairments (for example, Dockrell and Lindsay (1998)). The child could read the passages in the assessment either in sign or orally. No child in the present sample, theoretically, should be at a disadvantage because of their chosen communication mode.

Procedure

In a filmed testing session the children were administered the reading task following published manual instructions. The child read the passages 'aloud' and was asked questions about the passage immediately after reading it. The published discontinue rule was followed. If the child made a specific number of mistakes while reading the passage then the task was stopped. The discontinue rule applied only to the reading accuracy score. If the child had read the passage accurately but was unable to answer the comprehension questions, the task continued onto the next passage.

The children in the present study showed a wide range of communication abilities. Some children only signed, while others read aloud. There were also other children who read the stories using a combination of sign and speech. Of those children who read the passages out aloud, there was a range of clarity in their speech. Because of the wide range of communication abilities and the varying clarity displayed by the children the accuracy scale was not focused upon here. It was felt that it was difficult (and sometimes inappropriate) to judge the children on their pronunciation. Although it was the original intention to obtain an accuracy score, this was abandoned. A reading comprehension score was obtained.

3.2.3.3 Receptive language

A measure of the child's receptive language was also used. The decision to include this measure was made after it was ascertained that there was a floor effect in the reading comprehension test. A measure of receptive language that was appropriate for all the children regardless of their preferred mode of communication and their language proficiency was desired. Two sub-tests designed to measure receptive language from the CELF-R were administered, one designed for hearing 5- to 7-year olds called 'Sentence Structure' and another designed for hearing 8- to 12-year olds called the 'Oral Directions' scale. It was not possible to administer the full age appropriate receptive language scale for the children. Piloting revealed that some of the age appropriate tasks were too difficult, even for children seen as linguistically competent. The two tasks administered in the present study were chosen because they required a minimum reliance on the child's expressive abilities; the mode of response was pointing to pictures.

Procedure

The child was administered the CELF-R tasks during the Summer term on the same day as taking the last maths test. The task was administered following the published English word order with sign support.

The instructions for the 'Sentence Structure' tasks published in the manual were followed but a few alterations were made to the vocabulary used. The test was written in the US so some of the words were changed to the more familiar English words. In question 3 the story told is 'the girl is crying because she lost her pet'. The word 'pet' was replaced with 'cat' so that the more familiar sign for cat could accompany it. The pictures shown as the distractors showed cats so it was felt that the meaning of the task was not changed much. The word 'store' was replaced with the word 'shop' in question 9. The word 'sundae' from the phrase 'ice cream sundae' in question 17 was omitted so the phrase was left as 'ice cream'. The word 'mailman' was replaced by the word 'postman'. The word 'garbage' was replaced by the word 'rubbish' in question 23.

The published instructions for the 'oral directions' task were followed with two modifications. The children were required to point to a list of shapes in the order mentioned after the whole list had been recited. The aim of the task was to assess whether the child could understand, and respond to, a list of instructions of increasing length and complexity. The piloting of the task revealed that the children pointed to all the mentioned shapes simultaneously, even if they were told in the instructions not to do so. To make it salient that the child had to point to the mentioned shaped in the order mentioned in the instructions, the word 'next' accompanied by the sign was included. In the original instructions, the indication that the child should proceed to point at the shapes mentioned were indicated with the instruction 'go'. The children in the piloting of the task showed some confusion with this. The word 'go' was replaced with the word and appropriate sign 'now'. For example the original instruction for the first question in the task was 'Point to the black circle; point to the white square. Go.' This was changed to 'Point to the black circle; next; point to the white square. Now.' The remaining published procedures were followed for the rest of the task, including discontinuation after four consecutive failures.

3.3 Descriptive Results

The results are presented in two sections. The first section describes the results of the mathematics assessment. The second section makes comparisons between the hearing and hearing impaired children on the other assessments. Some tasks were only presented to the hearing impaired children, in these cases their performance is compared to standardised norms based on hearing children. This section attempts to answer the following question: 'Are the hearing impaired children in the present sample behind the hearing children on measures of cognitive, linguistic and numerical ability?'

3.3.1 Mathematics attainment

3.3.1.1 Testing session 1 – NFER-Nelson 7-11 Mathematics series "NFER (1)"

When the raw scores were converted to standardised scores using the published procedure 33 hearing impaired children obtained a score. The mean standardised score was 81.97 (*S.D.*=10.35). Standardised scores could not be calculated for nine children because they obtained raw scores too low to be converted to a standardised score following the published procedure. The manual only publishes scores two standard deviations above and below the published mean of 100. The result of the standardised test was the dependent variable for a large part of the analysis in this study. To avoid having missing subject data, and for the purposes of analysis only, the scores for those children with scores below a standardised score of 70 were extrapolated. The alternative approach of using raw scores was not possible in this case because the children in the two year groups had been administered different tests, according to their age. It was possible for the older children in the later testing session to obtain a raw score of 5, for example, and not be able to convert it to a standardised score. As described in the procedure section, the children obtaining a raw score of 5 were given a 'standardised score' of 69. A raw score of 4 was given a standardised score of 68. A raw score of 3 was given a 'standardised score' of 67; those children with a raw score of 2 were given a 'standardised score' of 66. Finally, those children obtaining a raw score of 1 were given a 'standardised score' of 65. The mean standardised score with the extrapolated scores was 78.31 (*S.D.*= 11.64).

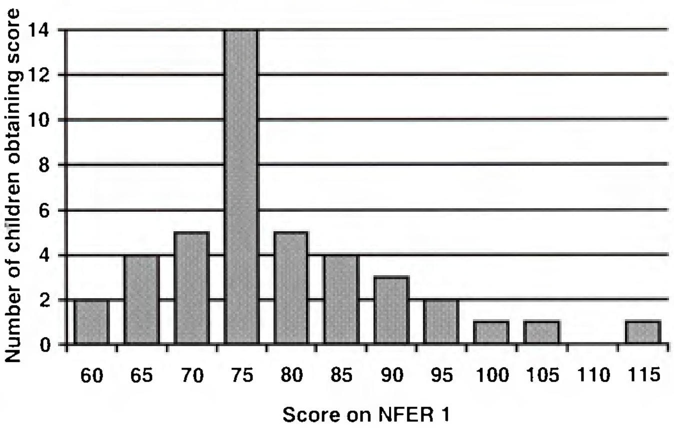


Figure 3.9 – Distribution of scores by hearing impaired children in NFER (1) test (extrapolated scores included, n=42)

The distribution of the scores was examined to see if it was significantly skewed Howitt & Cramer, 1997). The z-score was 2.16, which indicates that the data were significantly skewed.

For the purpose of analysis, the scores were normalised by taking the natural logarithm of the variable (Wright, 1997). This was carried out so statistical tests that assume normally distributed data could be used to analyse the mathematics scores. The standardised scores are presented in the tables for ease of reading and for comparison with later assessments. However, the statistical results reported are based on analysis with the normalised data.

3.3.2 Comparison with hearing children

The NFER-Nelson mathematics '8' and '9' tests were administered to hearing children taking part in the study during the Autumn term of the school year. It was possible to make a direct comparison of the scores obtained by both these groups of children.

The mean standardised score for the hearing children was 94.17 (*S.D.*=10.38). It was not possible to calculate a standardised score for two children because they obtained raw scores that could not be converted to a standardised score following the procedure published in the NFER-Nelson manual. The scores for these two children were extrapolated in the same manner described previously for the hearing impaired children. The mean score after extrapolation was 92.68. A comparison of the scores, including the extrapolated scores, shows that the hearing children obtained higher mean standardised scores than the hearing impaired children.

Table 3.3 Mean standardised scores of NFER-Nelson (1) by hearing status and National Curriculum year group including extrapolated scores.

Hearing status	**Year Group**	**Mean**	*S.D.*	**n**
Hearing	3	86.77	9.35	13
	4	95.88	12.10	24
	Total	92.68	11.92	37
Deaf	3	72.77	6.21	22
	4	84.40	13.24	20
	Total	78.31	11.64	42

An ANOVA analysis was carried out with the standardised score as the dependent measure and hearing status and year group as two factors showed a significant effect of hearing status (F (1,2)=26.57, $p < .001$) and a significant effect of year group (F (1,2)=17.61, $p < .001$). There was no interaction between year group and hearing status (F (1,2)=0.26, $p = .61$). The summary table is included in Appendix B. The hearing children obtained a significant higher mean score than the deaf children. The children in year 4 obtained a significantly higher mean than the year 3 children. This result is not in the direction expected because the standardised test scores are supposed to control for age. It could be a feature of the sample or using this assessment early in the academic year.

3.3.2.1 Summary

The literature suggests that hearing impaired children will obtain results that are below those obtained by hearing peers. The present study confirms this; the mean scores obtained on all three assessments were below published means. In addition to this, the mean score obtained by the hearing impaired in the NFER(1) assessment was lower than the mean obtained by the hearing children taking part in the study.

3.4 Comparative Results - Are the hearing impaired children in the present sample behind the norms for hearing children in assessments of cognitive ability and language?

The purpose of the present study is to establish whether the hearing impaired children are behind in the various assessments. If it can be demonstrated that these children are behind then these assessments can be used as predictors for the longitudinal study.

3.4.1 WISC III-UK

The estimated IQ scores based on four performance scale sub-tests were used. The mean IQ score was 85.98 (SD=15.89). The IQ scores ranged from 53 to 134.

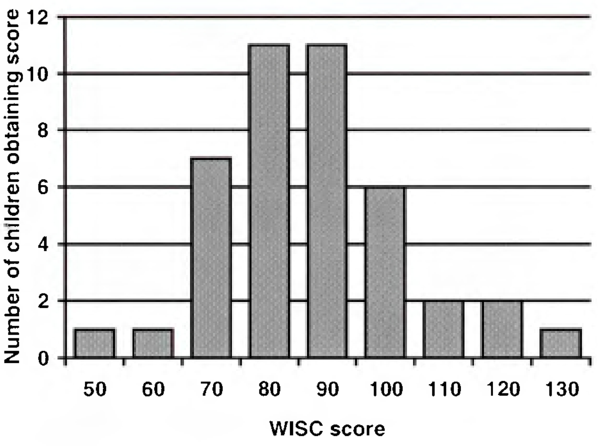


Figure 3.10 Distribution of IQ scores on the performance scale of the WISC-UK (n=42)

The mean IQ score was lower than the published mean of 100. This may be because children with additional needs were included in the sample. For example, one boy had mild cerebral palsy affecting his motor co-ordination; he obtained an estimated IQ score of 53. Another girl with a similar difficulty obtained a score of 85. Lastly, one girl had, until recently, lived in an orphanage in India. The teachers felt that her estimated IQ score of 71 reflected the lack of stimulation and education received by the girl prior to arriving in the country and being diagnosed and treated for her hearing impairment. When these three children were excluded from the analysis the mean performance IQ was 87.59 (*S.D.*=14.80), this is still quite low. Despite these additional difficulties, these three children were included in the sample because they all showed understanding in the mathematics assessments and the other tasks administered to them. Additionally, the inclusion of these children in the sample increased the range of IQ scores.

This result of a lower IO score was surprising because the literature suggests that the deaf obtain performance IQ scores that are not significantly different to their hearing counterparts (Braden, 1994). This raises concern when making conclusions about differences in task performance by the deaf and hearing children. Lower scores in the tasks could be a result of these lower IQ scores and not task specific. Analyses comparing task performance could not control for intelligence by co-varying IQ because the hearing children were not administered the task. Conclusions about the tasks can only be drawn after the relations between the task and mathematics attainment have been analysed controlling for IQ score in the predictive study.

3.4.2 Number processing

Researchers such as Epstein *et al.* (1990) and Hitch *et al.* (1983) have found a difference in the speed that hearing and hearing impaired subjects process number. Hearing and hearing impaired children will be compared on a number processing to examine whether the children taking part in the present study also demonstrate this difference. Number processing ability was assessed with a memory scan task that had been used in a previous study comparing deaf and hearing adults.

The children were asked to assess whether a previously presented digit was present in an array of different stimulus set sizes (SSS) ranging from one digit to six digits. Half the trials were positive probes (the original number was present in the array) and the other were negative (the original number was not present in the array). The accuracy of the children's responses was noted. Comparisons in levels of accuracy were made between the deaf and hearing children for the overall task and for the different SSS. From this, a memory capacity score was developed. The response times for each trial were also recorded. Again, comparisons were made between the hearing and deaf children, and for each SSS.

3.4.2.1 Accuracy

The hearing subjects performed the task significantly more accurately than the deaf subjects on the memory scan task. The mean number of correct responses obtained by the hearing children was 53.89 (*S.D.*=6.13) and the mean number of correct responses obtained by the deaf children was 47.83 (*S.D.*=8.03) out of a total of 60 trials. The distribution of the data were examined for skewness to establish if tests that assume normality of data could be used (Howitt & Cramer, 1997). The data were not significantly skewed (z=-0.72; *p*<.05). A t-test analysis for independent samples revealed that these means were significantly different (t (77)=3.73, *p*<.001). As the following graph shows, the number of accurate responses were not level throughout the task. Both the deaf and hearing children gave more correct answers for the smaller stimulus set sizes (SSS1 and SSS2). This suggests that the trials with the larger stimulus set sizes (SSS5 and SSS6) were more difficult for the children. Throughout the task, on each of the stimulus set sizes, the hearing children gave more correct responses than the deaf children.

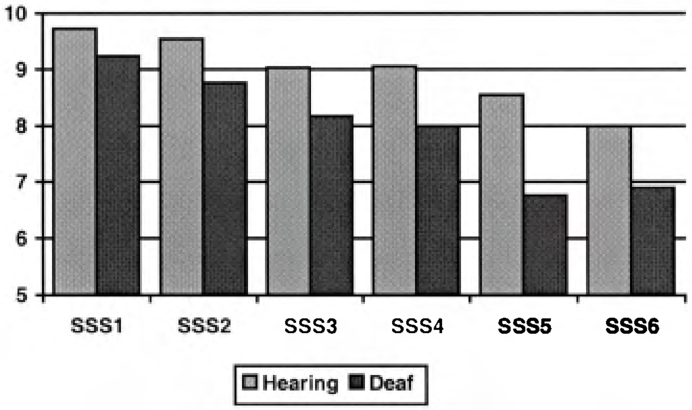


Figure 3.11 - Mean number of correct responses (range 0 to 10; n=80) for each SSS by hearing status

As can be seen in the graph the hearing children obtained a greater number of correct responses in each SSS. The mean levels of accurate responses decreased from 9.73 in stimulus set size (SSS) 1 to 8 (SSS6) for the hearing children, and from 9.24 (SSS1) to 6.90 (SSS6) for the hearing impaired subjects (A table is included in Appendix B). This suggests that the task increases in difficulty with increasing SSS. This was confirmed with a mixed design ANOVA with hearing status (hearing or deaf) as the between subjects factor and stimulus set size as the within subjects factor. Significant effects of hearing status on task performance (F(1,77)=13.92; *p*<.001) were revealed as were significant effects of stimulus set size (F(5,385)=40.19; *p*<.001). There was also an interaction effect of set size and hearing status (F(5,385)=2.95; *p*=.01). The summary table is included in Appendix B. This indicates that the overall levels of accuracy dropped as the stimulus set size increased and this drop in accuracy was more marked in the deaf than the hearing subjects.

3.4.2.2 Memory capacity

Epstein *et al.* (1990) suggested that at an accuracy rate of 82.4% the six-digit stimulus sets were beginning to 'tax the working memory capacity of the deaf subjects' (p. 343). For this reason a measure of working memory capacity was included. The cut-off point was chosen at 70%. The capacity score was obtained for the whole task by applying a pass/fail criterion for each SSS. If the child obtained seven or more correct trials in each SSS, the child was then given a pass mark (1). Failure to obtain seven or more items in each SSS correct obtained a 'fail' score (0). The child was essentially given six pass or fail scores that were totalled. These were added for each child and became the memory capacity score.

The distribution of the data was examined to examine whether statistical tests that assume normality of data could be used (Howitt & Cramer, 1997). The data were significantly skewed (z=2.18; *p*=.05) so distribution-free tests should be used to examine the data.

The mean capacity score for the hearing children was 5.59 (*S.D.*=1.07), the capacity score for the hearing impaired children was 4.67 (*S.D.*=1.49). These means were analysed with a Mann-Whitney test for independent samples and were found to be significantly different (Z=-2.83; *p*<.005).

3.4.2.3 Response Times

Following Epstein *et al.* (1990), the following section will examine the response times to the trials answered correctly. A comparison was made between the hearing and deaf subjects, positive and negative probes and the different stimulus set sizes.

The following graph shows the mean response times in seconds for the negative and positive probes for stimulus set size by the hearing and deaf subjects. The hearing subjects have, on average, quicker response times to both the positive and negative than the deaf subjects.

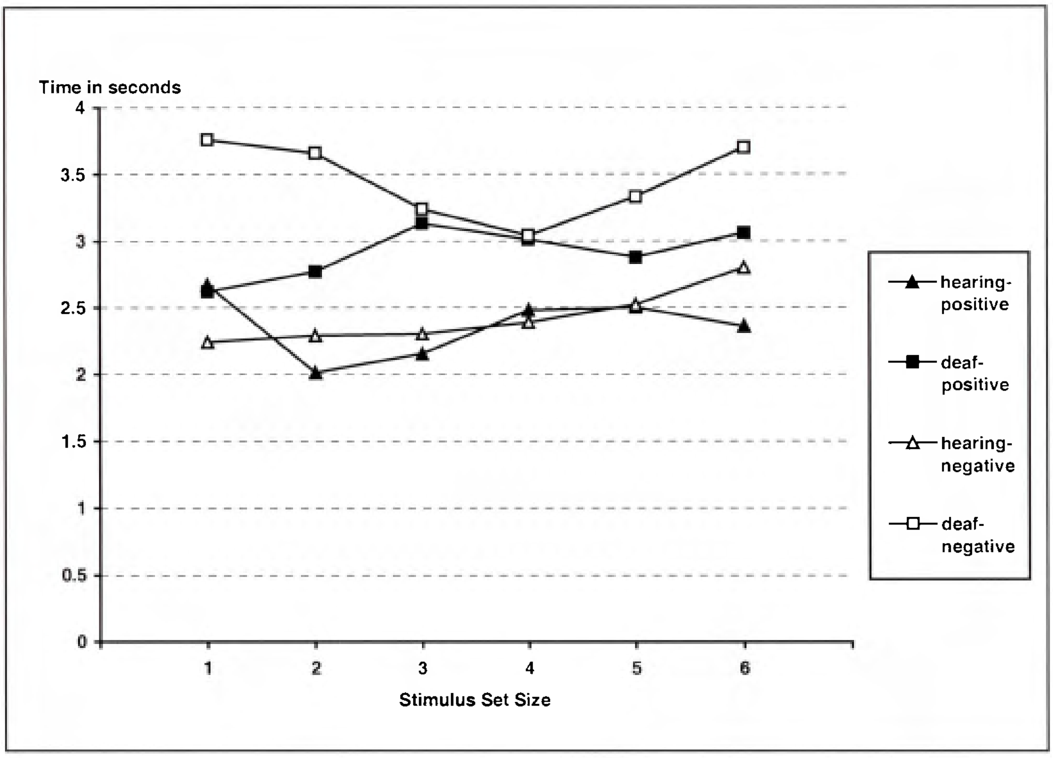


Figure 3.12 – Mean response times (in seconds) by hearing status and probe type for each stimulus set size

There were children who did not obtain correct answers for certain SSS trials. This influenced the number of subjects included in each analysis, the specific numbers of the children obtaining correct answers will be included in the following tables under column ‘n’.

Correct responses to negative probes

The following sections examine whether there are significant difference in processing between the hearing and hearing impaired children. This was examined by comparing the response times to the correct probes. For ease of reading the results of the negative and positive probes are presented separately.

Table 3.4 Mean response time (in seconds) to correct responses of negative probes in each stimulus set size by hearing status

SSS	**Hearing (*S.D.*)**	**Deaf (*S.D.*)**	**n**
1	2.24	3.64	h=37
	(1.03)	(2.06)	d=42
2	2.29	3.66	h=37
	(1.27)	(2.84)	d=41
3	2.30	3.24	h=37
	(0.83)	(1.96)	d=41
4	2.39	3.04	h=37
	(0.89)	(1.13)	d=41
5	2.52	3.33	h=36
	(1.02)	(1.34)	d=39
6	2.80	3.70	h=37
	(1.09)	(1.76)	d=40

A mixed design ANOVA with hearing status as the between subjects factor and the stimulus set size as the within subject factor with the response times as the response variable was carried out. There was a significant effect of hearing status (F (1,70)=11.70, p =.001). There was no significant effect of stimulus set size (F (5,350)=1.66, p =.14) and there was no significant interaction (F (5,350)=0.74, *p*=.60). The summary table is included in Appendix B. This suggests that the response times for correctly identifying a negative probe were significantly longer for the hearing impaired children in each of the stimulus set sizes. The response time increased as the stimulus set increased for the hearing children. This pattern of response time was not found for the hearing impaired children, the longer response times were found for SSS1 and SSS6 the quickest response time was for SSS4 (3.04 seconds).

Correct responses to positive probes

Table 3.5 Mean reaction time in seconds to correct responses of positive probes in each stimulus set size by hearing status

SSS	**Hearing (*S.D.*)**	**Deaf (*S.D.*)**	n
1	2.67	2.58	h=37
	(1.34)	(1.20)	d=42
2	2.01	2.71	h=37
	(0.60)	(1.55)	d=42
3	2.15	3.12	h=37
	(0.53)	(1.65)	d=42
4	2.48	3.00	h=37
	(1.74)	(1.68)	d=42
5	2.50	2.86	h=37
	(1.33)	(1.13)	d=40
6	2.36	2.95	h=37
	(0.87)	(1.08)	d=37

A mixed design ANOVA analysis with hearing status as the between subjects factor and stimulus set size as the within subjects factor, and the response time for correctly identified positive probes as the response variable revealed a significant effect of hearing status (F(1,72)=5.27, *p*=.025). A significant effect of stimulus set size was also found (F(5,360)=2.58, *p*=.03). There was no significant interaction (F(5, 360)=0.34, *p*=.89). The summary table is included in Appendix B. As the analysis for the negative probes indicate, the hearing children responded significantly more quickly than the hearing impaired children.

3.4.2.4 Summary

The hearing children in the present study obtained more accurate results in the memory scan task. For those test items answered correctly the hearing children obtained quicker response times. This has replicated the findings of previous studies, thus the first criterion of finding significant differences between the two groups, particularly of the hearing impaired children performing less well than the hearing children, is fulfilled.

The question remains as to whether this difference in number processing explains the difference between hearing and deaf students in standardised mathematics assessments. This will be explored by using the measures of memory capacity and response times as explanatory variables in the predictive study.

3.4.3 Shop Task

The Shop Task was administered to all the children taking part in the study. All but two of the hearing children were able to complete the task with no mistakes. The remaining two children made one mistake each resulting in a task score of 8. One child counted a '1p' counter as a '10p' counter when making 23p. The other child counted some 10p counters as 1p counters when counting 21p. On the following task, the boy realised his mistake and told the researcher that he had made a mistake on the previous trial. The trial was still marked as incorrect.

Not all the hearing impaired children obtained full marks in the Shop Task. Thirteen children were unable to score on the task. Eleven children obtained a score of 1 by correctly identifying the counter representing 5p. Nine children obtained a score of 9, and two children obtained a score of 8. The other children obtained scores between 2 and 5, and no child obtained scores of 6 or 7. Because of the essentially bimodal nature of this distribution, the scores were classified into categorical levels of understanding. Those children obtaining a score of zero or one were classified as showing no understanding of additive composition in the task. The children obtaining a score from 2 to 5 were classified as demonstrating an incomplete understanding of additive composition. The eleven children committing one or no errors were classified as having a good understanding of additive composition. Figure 3.13 shows the distribution of scores, by category, obtained by the hearing impaired children. If these same classifications are applied to the scores obtained by the hearing children, they all demonstrated good understanding of the additive composition of number. The extreme differences between the distribution of the children by categories in the two groups render it unnecessary to apply statistical tests to assess whether the differences are significant. It is safe to conclude that hearing children outperform the hearing impaired children in this task.

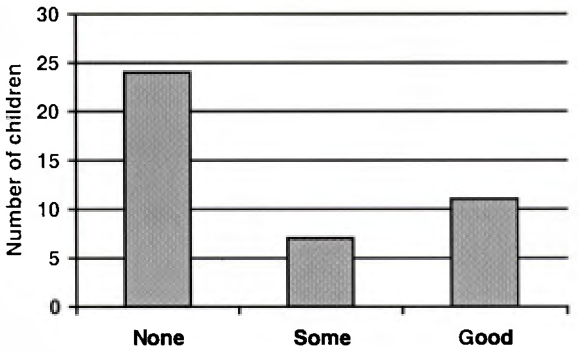


Figure 3.13 Number of children in each category of demonstrated understanding of additive composition of number in the Shop Task (n = 42)

3.4.3.1 Summary

The hearing impaired children demonstrated a delay in the acquisition of the concept of the additive composition of number in comparison to their hearing peers. Whereas all the hearing controls demonstrated a good understanding of the additive composition of number, over half of the hearing impaired children demonstrated no understanding of the additive composition of number. The first criterion of under-achievement by the hearing impaired children in comparison to their hearing peers has been fulfilled by this measure. The question remains as to whether this difference in knowledge of the number system explains the difference between hearing and hearing impaired attainment levels in standardised mathematics scores. The additive composition score was kept in the categories shown in the above graph for future analysis.

3.4.4 Mental operations involving time concepts

Sixty-four items intended for the assessment of mental operations involving time concepts were designed. Both the hearing and hearing impaired children were administered the task assessing comprehension of time concepts. Because of time restrictions, the hearing children were administered a shortened version of the task with half the number of items selected at random within each block of items. Thus, comparisons between hearing and hearing impaired children are based on 32 questions, whereas the prediction of mathematics scores presented in chapter 4 is based on 64 items.

3.4.4.1 Structure of analysis

The tasks were developed for the present study, so issues concerning the validity of these measures have to be addressed first before comparisons can be made between the hearing and hearing impaired children. For this reason, the tasks are initially analysed for reliability and validity. Having established that the measures can be used, then comparisons between the hearing and hearing impaired children can be made.

In the first section of this chapter, the rationale for the evaluation of the measures is presented. In each of the subsequent sections, the results of these assessments and the comparisons between hearing and hearing impaired children are described.

a) Reliability

Kline (2000) states that the coefficient alpha is regarded as the fundamental index of reliability. It indicates the expected correlation of a test of *k* items with an alternative form with *k* items. In other words, this measure of reliability is obtained through inter-item correlations within a task. If a set of items shows a high coefficient alpha, it is possible to conclude that all the items measure the same variable and thus to treat them as one test.

In tests with dichotomous items, such as the present tasks where each item is scored on a pass/fail criterion, a special variant of the co-efficient alpha is the Kuder Richardson 20 formula (KR20). The interpretation of the figure is the same as the coefficient alpha reliability (SPSS user's guide, 1983; p.717; Kline, 2000). The figure can be interpreted as follows: the reliability is a measure of 'true' versus 'observed' variance. A co-efficient of .85, for example, means that 15% of the variance is residual and 'irrelevant'.

The purpose of the analysis in the present study was to establish whether the measures designed were of sufficient reliability to be used as research tools. A reliability co-efficient of 0.7 or above is seen as sufficient for use as a research tool (Hammond, 1995). Thus, if the tasks meet this criterion it will be possible to conclude that they measure the same ability and to use a single score to represent all the items.

b) Validity

There are three facets of test validity that are considered important in test construction: content validity, criterion validity and construct validity. Content validity is often called 'face validity' and is the subjective evaluation of the relevance of the test items. It is often not given much credence because it lacks objectivity (Hammond, 1995). Criterion validity involves testing the hypothesised relationship of the test with external criteria. Two ways of examining this are to test the predictive validity of the test and to observe the relation between the measure of interest and tests administered at the same time (Hammond, 1995). Construct validity examines the internal structure of the measure by testing hypotheses about the results obtained from the test (Hammond, 1995; Kline, 2000). It was felt that a complete examination of criterion validity was not possible in the present study: the measure was developed for the study precisely because no assessments of the understanding of time concepts are available. Examination of the validity of the time concepts tasks concentrates on construct validity and one aspect of criterion validity, the relation between the measures and others administered simultaneously. If this analysis is considered satisfactory in the present thesis, subsequent analyses of content and criterion validity of the task could be assessed in future research.

c) Construct validity

One method of examining the construct validity of a measure is to assess its reliability through inter-item correlations: reliability is one aspect of construct validity. In this case the internal structure of the items is assumed to reveal high-item homogeneity (Hammond, 1995).

Another method involves fitting the observed responses to some kind of measurement model (Hammond, 1995) and this was the principal method of analysis in the present case. Specifically, the methods used to assess construct validity of the task in the present study are to establish that the sample is not responding in a random manner to the control items, and to make predictions about expected performance in the experimental items. The validation of a test or measure is an ongoing, cumulative process that is inferred from an accumulation of empirical and conceptual evidence (Hammond, 1995). Consequently, the validity of the time concept tasks is examined using a number of assessments in the present chapter with the reduced set of items administered to the hearing impaired and hearing children. Further analyses are included in the following chapter with the full set of items that were administered only to the hearing impaired children.

The distribution of scores was examined for information about the children's general response patterns. It was desirable to establish whether the children, as a population sample, were not answering in a random fashion throughout the assessment. To explore whether this was the case the distribution of scores were examined and compared to a binomial distribution model. This model was used as the comparison model because: the number of trials carried was known and finite; the trials were independent of each other; each trial had two outcomes, success or failure; and the probability of a successful outcome was assumed to be the same for each trial (Crawshaw & Chambers, 1997). Note that these criteria were fulfilled for the distribution of the raw scores only and not to any corrected scores calculated later. For this reason, comparison to the binomial model was carried out with the raw scores only.

The responses of hearing impaired and hearing children taking part in the study were analysed on the basis of group performance. For example, the mean scores of the two groups were compared and analysed. Even though it may be possible for any one child to obtain a number of correct responses to any item by chance, the interest was to examine the hearing and hearing impaired children as groups. For this reason, the group performance on the tasks was examined and compared to that predicted by binomial distribution through various applications of the formula generally abbreviated to *B(n,p)* (Crawshaw & Chambers, 1997). The following formula gives the probability of *r* successes out of *n* independent trials when: the probability of success at any trial is *p*; *r* ranges from 0 up to *n;* *r* has to be a whole number; and values of *r* outside the range 0 to *n* produce probabilities of 0.

For a given *r*, *n*, and *p*, the probability of exactly *r* successes out of *n* trials is:

$$\frac{n(n-1)(n-2)\ldots(n-r+1)}{r!}p^r(1-p)^{n-r}$$

(Woodhouse, personal communication; but see also Bunday & Mulholland, 1983; Crawshaw & Chambers, 1997). There are occasions when the figure given as the probability is very small e.g. 0.00000057. In these cases, for ease of reading, the scientific notation will be used, for example the figure just given is written as: 5.7 x 10^{-7}.

The null hypothesis for this analysis is that the distribution of scores on the control items does not depart from a random distribution. If this hypothesis is not rejected then it cannot be concluded that the task is measuring the concepts under investigation. It also introduces doubts as to whether the task instructions were understood by the participants. Rejecting the null hypothesis shows that performance was better that chance and this indicates that the children understood the instructions.

No such predictions were made about the chance performance levels of the scores obtained on the experimental items because these were designed for a different purpose. Goldstein and Lewis (1996) stated that one of the purposes of assessment is to certify or qualify individuals by discriminating among them. It was with this purpose that the experimental time concept tasks were designed. In other words, the experimental items were designed to discriminate among the differing levels of understanding of the time concepts held by the children taking part in the study. Siegler (1995) identified three possible groups of children when assessing change in children's understanding of concepts. The groups were based on the response patterns demonstrated to conservation tasks: those children demonstrating an understanding of the concepts being assessed; those who demonstrate no understanding of the concepts; and those who fluctuate using different strategies, which may be appropriate or inappropriate. In assessments this would lead to three different patterns of performance when comparing to chance levels. Those who perform below chance levels because they consistently adopt an incorrect strategy in spite of understanding the task instructions; those who perform well above chance levels because they consistently apply appropriate strategies; and those around chance level performance who show the most variation because the strategies applied vary between one or more appropriate or inappropriate strategies. There is an observation that fluctuating behaviour is not taken into account by the test response. In addition, one should consider the possibility that the respondent may be guessing the answer to a test item (Kline, 2000).

The experimental items were designed with the purpose of discriminating between the children. It was with this aim in mind that the following prediction was made: it was predicted that the children would show a greater range of scores as they demonstrate varying levels of ability to make inferences involving time. For the experimental items it was also predicted that the hearing children would show a significantly higher number of correct responses than the hearing impaired children. It was not predicted that all the children perform at levels above chance, as previously done in the control items, because it was not expected that all the hearing impaired children would fully comprehend concepts of time.

d) Criterion validity

As mentioned previously, criterion validity involves analysing the hypothesised relation between the test and external criteria. Two ways of examining this are to test the predictive validity of the test and to observe the relation between the measure of interest and tests administered at the same time (Hammond, 1995). The present study examines two aspects of criterion validity: the relations between the time concept measures amongst themselves; and the relation with these tasks and the mathematics assessment administered in the same testing period. If the measures are significantly correlated, then this strengthens the validity of the time concept measures.

e) Correction for 'guessing'

In models of test response certain assumptions are made about both the nature of the items in the test and the behaviour of the person taking the test. With the traditional model, or the 'classical model of test error', it is assumed that for any latent trait (such as intelligence) each person has a 'true' score, which may be achieved on any occasion. The *obtained* test score (such as IQ) differs from the true score on account of random error (Kline, 2000). The probability of responding correctly to an item is a function of a person's position on a latent trait dimension. Further expansion of this assumption has led to the creation of alternative test response models such as the Rasch model. (A full and complete description of these models is beyond the scope of the present thesis but the reader is referred to Kline, 2000). The Rasch model takes into consideration that not all the items on a test are the same. They may vary in difficulty and in the ability to elicit the latent trait being assessed. In other words, each test item varies in the degree to which the person's latent trait can be elicited. This means that not only does the person hold a position on a latent trait dimension, each test item also holds a position on the latent trait dimension. The models have been criticised as being incomplete (Kline, 2000), both these models assume a degree of consistency in the tested person's behaviour, and this is not always the case.

There is a debate as to whether one should adjust raw scores obtained when the possibility of guessing is introduced. It can be argued that there is no need to correct scores for guessing in multiple choice tests. Any observed score will be a sum of the true score plus the number of responses that were correct by chance. Because everybody has the same probability of obtaining a correct response by chance, there would be no need to correct scores for guessing. The NFER mathematics assessment used in this thesis is an example of a standardised assessment that does not include a correction for guessing.

Kline (2000) considers it necessary to use corrections for guessing in assessments because the test response models, particularly the Rasch model, do not adequately address them. Guessing introduces noise in the measure in many ways. Most importantly, if a correction for guessing is not used it is not possible to discriminate between two subjects with the same score but differing levels of ability, one who answered all the items – and thus guessed in those that were beyond his or her ability – and one who only answered the items that he or she actually knew how to solve.

There are various formulae that correct for guessing in multiple-choice or forced-choice tasks. One formula put forward by Kline (2000) was $C = R - (W / N\text{-}1)$. Another formula put forward by Rust and Golombok (1989) is $C = (R\text{-}W) / (N\text{-}1)$. In each case C is the corrected score, R is the number of correct responses, W is the number of incorrect responses, and N is the number of alternatives available (Rust & Golombok, 1989). Kline (2000) indicates that the use of any of these formulae is acceptable. They do, however, have their limitations because certain assumptions are made. Firstly, the formula assumes that all the wrong responses are a result of guessing - this is not necessarily the case. As argued by Siegler (1995), children may consistently be adopting an incorrect strategy because they do not understand the concept being assessed. Note that correction for guessing in this case will produce negative scores. Thus the scoring system will still discriminate between systematic and random error, where the corrected score will approach zero (if the subject guessed on all the items) or be positive (if the subject guessed only in some items and knew the response to other items). Secondly, where guessing has occurred the formula assumes that there is an equal chance of choosing each of the distractors. This is also not always the case, some distractors may initially be eliminated by the participant leaving fewer options from which to guess. The scores that result from this formula may underestimate the performance of participants behaving in this manner. Lastly, the results from this formula are applicable to groups of participants on average, but in individual cases it may be wrong (Kline, 2000).

This does raise the important issue, however, of what to do in tests where guessing can occur, such as the time concept tasks. It was decided, in the present instance, to adopt a formula correcting for guessing for a number of reasons: the children responded to all the items; there were relatively few items on the task; and the number of options available to the child on each item was small. These last two factors increase the risk of guessing (Kline, 2000). The formulae presented above were applied to the raw scores producing differing corrected scores but the same results from statistical analyses. So, to avoid repetition, the modified scores derived from the formula presented in Kline (2000) are reported. The modified scores were used for all the subsequent comparative and predictive analyses. The analyses of reliability and chance performance in the control items are based on the observed scores.

f) Comparison between hearing and hearing impaired children

After analysing the reliability and validity of each time concept task, the comparisons between the hearing and hearing impaired children are presented. These are based on the corrected scores. The distributions of the corrected scores are examined first to test for skewness; this will indicate which statistical test is most appropriate.

A number of predictions were made about the comparison of scores. On the control items the hearing and hearing impaired children are expected to obtain scores above chance level, and ideally show near or at ceiling performance. In this case there should be no significant differences in performance between the two groups. If these levels of performance are obtained, then it can be concluded that the instructions in these tasks were understood by the children. The control and experimental items place the same linguistic and memory demands on the children. Consequently, if it is shown that the children understand the control items but have difficulty with the experimental items, it will be safe to conclude that the difficulty stems from the need to make inferences, which is present in the experimental items and not in the control items. If significant differences are observed in the control items, then the score in the control items will have to be included as a co-variant in future analyses comparing the hearing and hearing impaired children.

Differences in performances between the two groups were expected in the experimental items. It was predicted that the hearing children would obtain a significantly higher number correct responses in the experimental items.

The comparisons will be carried out both by subjects and by items. The mean scores by item and by subject are the same but the analysis by items is based on the standard deviations of the items with respect to the mean and offers a different perspective of the results.

3.4.4.2 Reliability

The time concept tasks were administered in two sets of items, the control and the experimental items. The investigation of the validity of the measures in the present section is based on a randomly chosen, reduced set of 16 items which was half the total number of items which had been administered to the hearing and hearing impaired children. Eight of these were experimental items and required the use of place-holders (P-HR), and eight were the control items not requiring the use of place-holders (NP-HR).

The reliability coefficients of the items assessing the Place-holder task was KR20=.74. This is an acceptable level of reliability (Hammond, 1994). The analysis was repeated for each group defined by hearing status (Hearing KR20=.70 and Hearing impaired KR20=.76). These are also acceptable levels of reliability.

The reliability coefficients of the items on the Inversion task was KR20=.74, which is acceptable. The analysis was repeated for each group defined by hearing status (Hearing KR20=.74 and Hearing impaired KR20=.68). This coefficient is acceptable for the hearing children but just below the level suggested by Hammond (1994).

The reliability co-efficient for the Change task items was KR20=.69. The analysis was repeated for each groups defined by hearing status (Hearing KR20=.-.05 and Hearing impaired KR20=.67). These coefficients all fell below the recommended cut-off point and may be a result of the small number of items included in the analyses. The hearing children showed a ceiling effect on the task items task so the results may reflect the task's low levels of discrimination. A more in depth analysis of the inter-item correlations revealed that if one item (Change decrease 45) was removed from the scale, the reliability co-efficient increased to .73. This is an acceptable level of reliability. This task was then analysed using the seven items that increased the task's reliability.

The measures used to assess time concepts were found to be reliable. Thus it can be concluded that the items within each of the tasks, Place-holder and Inversion, are measuring the same ability.

The results for the Change task indicate that the results should be interpreted with caution given the low level of reliability obtained for the hearing children. This low reliability cannot be attributed to the fact that two types of items were used, Change increase and Change decrease, because these tow halves were significantly correlated (ρ=.33; *p*=.003) and therefore measured the same construct. This low reliability for the hearing children is likely to result from their performance being at ceiling level.

3.4.4.3 Construct validity

The present section assesses the construct validity of the measures by examining performance on the control items of these tasks. It was not possible to design control items for the Change task so an alternative methods for ensuring that the children had understood the instructions and reducing bias in the responses were designed. The children had to repeat the instructions before giving their response to ensure that the children had understood the 'story'. In addition, differences in the items were introduced to reduce bias in response. In some items the number of objects reduced, in other they increased. This ensured that systematically choosing one type of picture would not always give a correct response.

It was predicted that the children would perform at levels significantly above chance on the control items. The analysis is carried out for the two tasks with control items: the Place-holders task and the Inversion task.

The control items were designed to establish whether the children had understood the instructions of the task. The analyses focus initially on the control items as part of the assessment of construct validity. If the children, as a group, perform at levels that are above chance on the control items, then one can assume that the task was generally understood. After this has been established, analysis of the experimental items can take place.

Place-holder task

The control items for the place-holder task (NP-HR) were administered to the whole sample of 79 hearing and hearing impaired children and the distribution of the scores was examined.

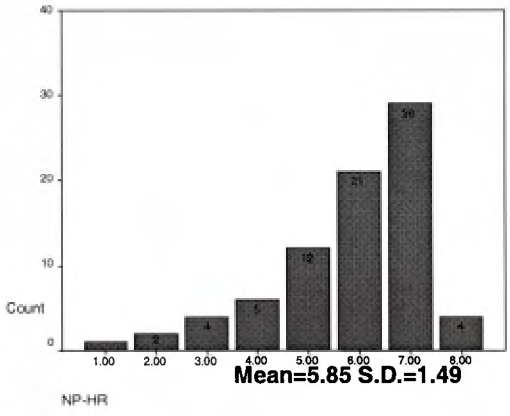


Figure 3.14 Distribution of scores on the Place-holder task control items in whole population

The probability of giving a correct response by chance for each item was 0.25 because there were four alternatives. The mean number of correct responses expected by chance is thus two out of eight trials. A cut-off point of three, that is only scores above the expected chance level, was used in the analysis. The binomial probability of one child obtaining a score above two, that is, 3 or more correct items by chance out of 8, was 0.32. As can be seen in figure 3.14, 76 out 79 children obtained a score above two on the control items requiring no place-holders. The binomial probability of this distribution occurring by chance was 8.75 x 10^{-34}.

The analysis was repeated for each group defined by hearing status. It is summarised in table 3.6. It can be seen that both the hearing and hearing impaired groups were performing significantly above chance level. It should be noted that the probability of the event *not* occurring is one minus that of the event occurring. In other words, the probability of only two hearing children did not scoring above chance was 1 – 1.77 x 10^{-19}, i.e. it is possible that they were behaving randomly. For this reason these values are not given because they can be calculated easily.

Table 3.6. Number of children obtaining scores above and not above chance level (level set at 0.25 x 8) on the control items by hearing status (probability of event occurring in brackets)

Place-holder task – control items	**Hearing**	**Hearing impaired**
Above expected chance level	35 (1.77 x 10^{-19})	41 (1.04 x 10^{-10})
Not above expected chance level	2	1

Thus, it can be concluded that it is highly unlikely that the two groups of children obtained this pattern of results by chance. This suggests that the children in both groups understood the task instructions. The confidence in the construct validity of the Place-holder measure is strengthened because the children were not responding at random to the control items.

Inversion task

The analysis reported above is repeated in the present section with the Inversion task items. A reduced set of items, half the total number chosen at random, was administered to the whole sample of hearing and hearing impaired children. The probability of giving a correct response by chance for each item was 0.5 because there were two alternatives. This gives two correct responses out of four trials by chance. On this reduced set 62 out of 79 children obtained scores above chance level for the control items requiring no inversion. The binomial probability of one child obtaining 3 or above correct items by chance out of 4 was 0.31. As can be seen in figure 3.15, 62 out 79 children obtained a score above two on the control items requiring no inversion. The binomial probability of this occurring by chance was 7.47 x 10^{-18}.

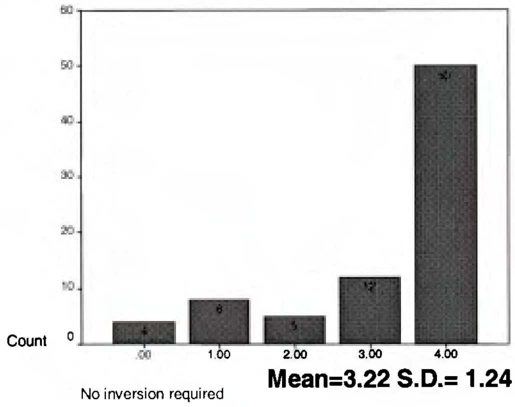


Figure 3.15 Distribution of scores on the control items (No inversion required) for whole sample

The analysis was repeated by hearing status. Table 3.8 summarises the number of children above or below the expected chance levels. The number in brackets indicates the probability of these results occurring by chance.

Table 3.7 Number of children obtaining scores above and not above expected chance level (level set at 0.5 x 4) on the control items by hearing status (probability of event occurring in brackets)

Inversion task – control items	**Hearing**	**Hearing impaired**
Above chance level	35 (6.74 x 10^{-16})	27 (1.07 x 10^{-5})
Not above chance level	2	15

It is highly unlikely that the two groups of children obtained this pattern of results by chance. This indicates that the children understood the task instructions. The confidence in the construct validity of the measures is strengthened because the children were not responding at random to the control items in the Inversion task.

Summary

Two tasks had control items, the Place-holders task and the Inversion task. It was found that the hearing and hearing impaired children were performing at levels that were highly unlikely to have occurred by chance on these control items. This increased confidence in the construct validity of the tasks.

3.4.4.4 Criterion validity

The criterion validity of the time concept tasks was assessed by examining the correlations between the different tasks, and by examining their relation with the mathematics assessment administered during the same testing session.

Table 3.8 Spearman's Correlation matrix of time concept tasks and NFER(1) for whole sample

	NFER(1)	**Change**	**Inversion**
Change	.63		
	$p<.001$		
Inversion	.38	.39	
	$p=.001$	$p=.001$	
Place-holders	.54	.48	.36
	$p<.001$	$p<.001$	$p=.001$

All the tasks were significantly and positively correlated with each other, and with the mathematics assessment. The strongest correlations were with Change and Place-holders tasks.

These results strengthen our confidence in the validity of the Place-holder and Change tasks.

The analysis was repeated by hearing status and is summarised in the table 3.9 below. Those coefficients in the shaded area *above* the diagonal in bold font refer to the hearing impaired children, those below refer to the hearing children.

Table 3.9 Spearman's Correlation matrix of time concept task and NFER(1) by hearing status (Numbers above the diagonal in bold in shaded area refer to the hearing impaired children and those below to the hearing children)

	NFER(1)	**Change**	**Inversion**	**Place-holders**
NFER(1)		**.34** ***p*=.03**	**.08** ***p*=.62**	**.61** ***p*<.001**
Change	.24 *p*=.15		**.34** ***p*=.03**	**.52** ***p*<.001**
Inversion	.48 *p*=.003	.18 *p*=.28		**.39** ***p*=.01**
Place-holders	.41 *p*=.01	.15 *p*=.38	.19 *p*=.26	

The results for the hearing children summarised in table 3.9 show that the Inversion and Place-holder tasks were both positively and significantly correlated with NFER(1). The tasks were not correlated with each other.

Table 3.9 shows that in the hearing impaired sample the Change and Place-holder tasks were significantly correlated with NFER(1). The Inversion task was not significantly correlated with mathematics score. The tasks were all correlated with each other.

The results suggest that the Place-holders task meet all the criteria for the hearing impaired children but only partially for the hearing children. Support for the idea that Inversion task is a valid measure for use with hearing impaired children is not obtained. Support for the idea that the Change task is a valid measure was strengthened for the hearing impaired children but not for the hearing children. The negative result obtained for the Change task may be due to the ceiling effect obtained in this task for the hearing children. If this is the case, then there should be significant difference in performance on the Change task between the two groups. This is explored in the following section comparing the groups on task performance.

3.4.4.5 Comparison of scores

Place-holders task

The scores were corrected for guessing by applying the formula presented by Kline (2000). The distribution of the corrected control scores was tested for skewness to establish whether statistical analyses that assume normal distribution could be used to analyse performance on this task (Howitt & Cramer, 1997).

It was expected that the distribution of scores in the control items would be skewed because of the need to design items that assessed the comprehension of the task instruction. This was confirmed, the distribution of the scores obtained by the whole sample (figure 3.16) were confirmed as significantly skewed (z=-4.16; *p*=.05).

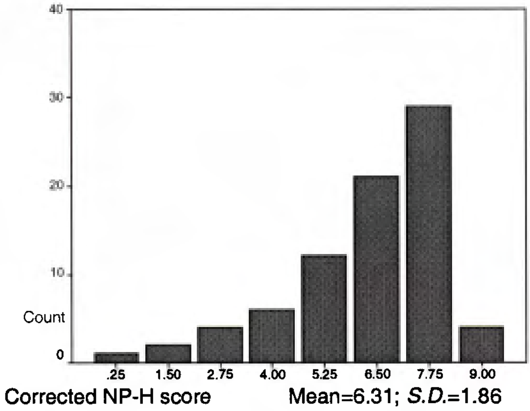


Figure 3.16 Distribution of corrected control scores by whole sample

The analysis was repeated by group and can be seen in figure 3.17. Analysis of the distribution of the scores by group revealed that they were significantly skewed for both groups of children (Hearing z= -3.85; *p*=.05; Hearing impaired z= -2.21; *p*=.05).

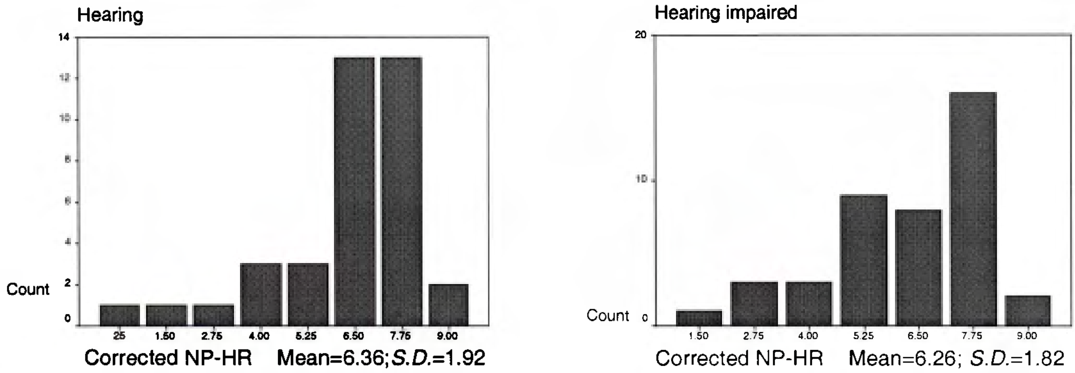


Figure 3.17 Distribution of the corrected control task scores by group

Statistical tests that do not assume the normal distribution of data should be used to analyse the data obtained from the control items of the Place-holders task.

The distribution of the corrected scores for the experimental items of the Place-holders task is presented in figure 3.18 below.

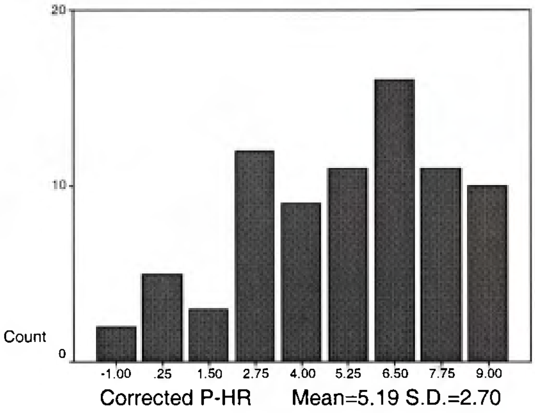


Figure 3.18 Graph of distribution of corrected experimental (P-HR) scores for whole sample

Although the scores for the whole sample appear to be negatively skewed, they were not significantly so (z=-1.58; *p*<.05). This analysis was repeated by group as defined by hearing status.

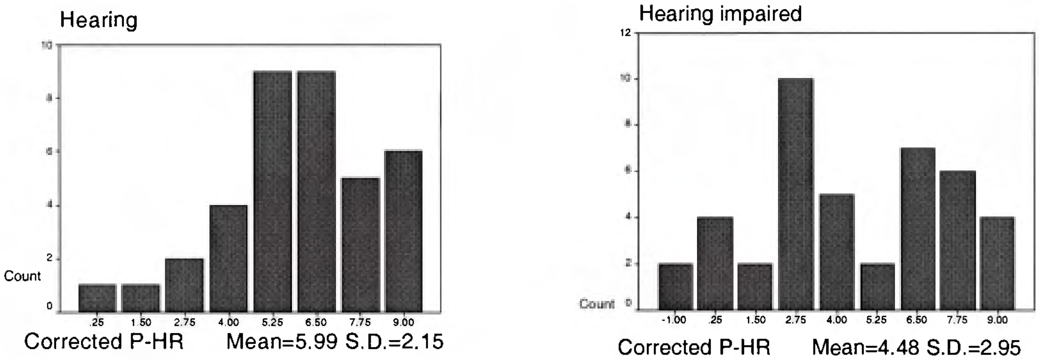


Figure 3.19 Distribution of corrected experimental (P-HR) scores by hearing status

The distribution of the scores appeared to be negatively skewed on the graph (figure 3.19) for the hearing children but it was not significantly so (z= 1.46; *p*<.05). The distribution of scores obtained by the hearing impaired children were also not significantly skewed (z=0.26; *p*<.05). So, the distributions of scores were not significantly skewed, and parametric statistical tests can be used to analyse the corrected experimental data.

It was predicted that there would be no significant differences in performance on the control items between the groups. The mean rank of correct responses obtained by the hearing children was 40.95 and the mean rank for the hearing impaired children was 39.17. A Mann Whitney U test with the modified scores on the control items was used because the distribution of scores was significantly skewed. There were no significant differences between the two groups of children on the control items (Z=-.36; *p*=.72).

It was predicted that significant differences in the mean corrected experimental scores obtained would emerge between the groups. A t-test analysis of the corrected scores obtained on the experimental items was carried out and a significant difference was found between the two groups (t (74.57)= 2.63; *p*=.01). The hearing children obtained significantly higher scores in the experimental items than the hearing impaired children and this confirmed the predictions made.

The analysis was also carried out by item. The percentage of children answering each item correctly is presented in Appendix B. The range of correct responses per items was from 16.2% to 97.3%.

Two analyses were carried out to examine the differences between the two groups of items within each hearing status group separately. A Mann Whitney U analysis was carried out in each case comparing the control items and the experimental items. For the hearing children the mean rank for the control items was 10.44 and the mean rank for the experimental items was 6.56 and this difference was not significant (Z=-1.64; *p*=.11). The mean rank of the control items (NP-HR) for the hearing impaired children was 11.31 and the mean rank for the experimental items (P-HR) was 5.69; this was significantly different (Z=-2.37; *p*=0.02).

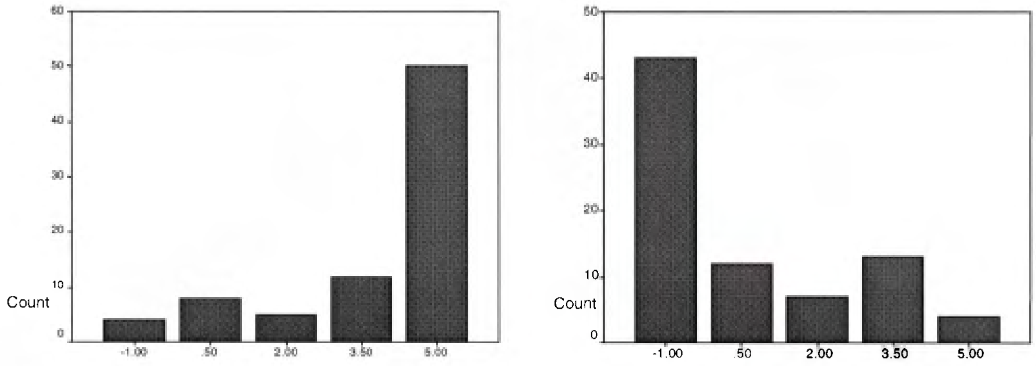
This confirms the results of the analysis carried out by subject. There were no significant differences between the two sets of items for the hearing children. The hearing impaired children found the experimental items significantly more difficult than the control items in the Place-holder Task.

The question that remains to be investigated is whether this task is predictive of mathematical attainment in the present group of hearing impaired children. This question is examined in the following chapter.

Inversion task

The scores were corrected for the possibility of guessing using the formula put forward by Kline (2000). The distribution of the scores was examined to establish whether statistical tests that assume normal distribution of scores can be used to analyse the data.

Examination of the distribution of the scores obtained by the whole sample (figure 3.20) suggests that the scores for the control items were significantly skewed. This was found to be so (z=-5.25; *p*=.05). The scores for the experimental items were also found to be significantly skewed (z= 3.42; *p*=.05).



Corrected No inversion required Mean=3.82; *S.D.*=1.86

Corrected Inversion required Mean=.54 *S.D*=1.99

Figure 3.20 Distribution of corrected scores for control and experimental items for the whole sample

The distribution of the corrected control items was also examined by group (figure 3.21). These distributions were also significantly skewed for the hearing children (z=-8.50; *p*=.05) and for the hearing impaired children (z=-2.04; *p*=.05).

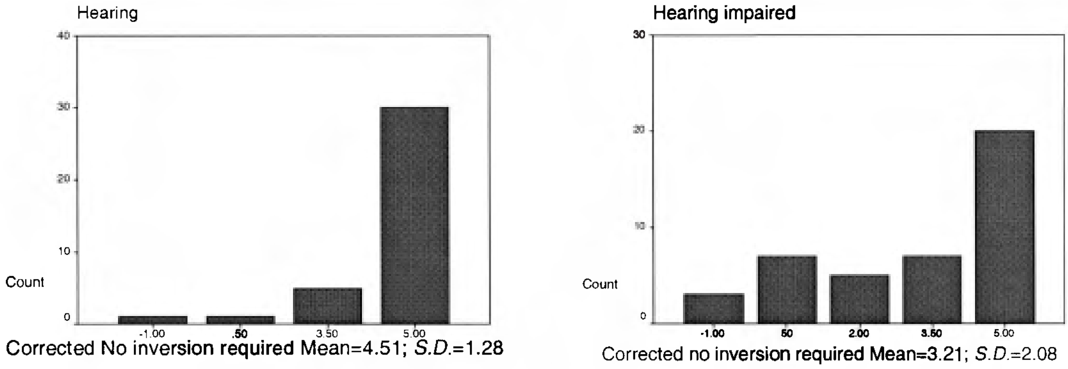


Figure 3.21 Distribution of the scores on the corrected control items by group

The distribution of corrected scores on the experimental items was also examined by groups as defined by hearing status and can be seen in figure 3.22. The distributions of the scores were not found to be significantly skewed for the hearing children (z= 1.34; *p*<.05) and were found to be significantly skewed for the hearing impaired children.

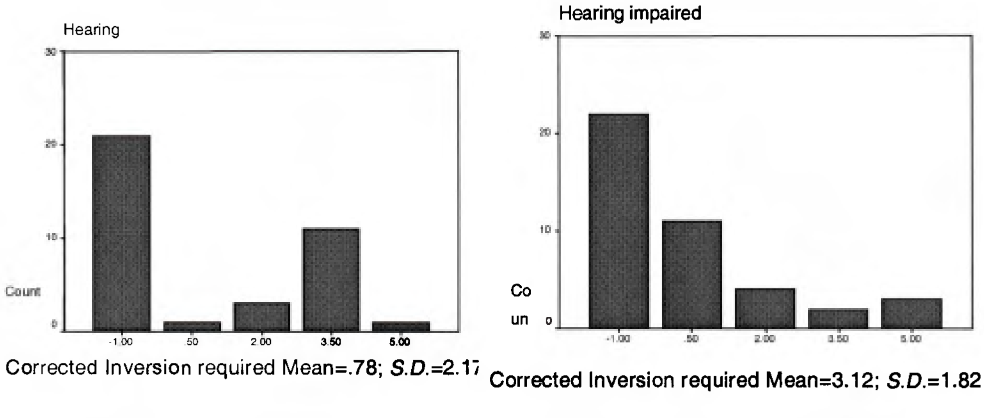


Figure 3.22 Distribution of corrected experimental items by hearing status.

The majority of data were skewed so distribution-free statistical tests should be used for analysis.

The mean ranks obtained in the control items were analysed to investigate group differences in performance. It was predicted that there would be no significant differences between the groups because these were control items. The mean rank obtained by the hearing children was 47.66. The mean rank for the hearing impaired children was 33.25. A Mann-Whitney U test revealed that these differences were significant and the hearing group obtained a significantly higher number of correct responses (Z=-3.23; *p*=.001).

The prediction was not supported. There were significant differences between the two groups in the control items.

Performance in the experimental items was also examined. It was predicted that the hearing children would perform better in the experimental items than the hearing impaired children. The mean rank in the experimental items was 41.22 for the hearing children and 38.93 for the hearing impaired children. This difference was not significant (Z=-.49; *p*=.63).

The prediction was not supported. There were no significant differences between the two groups.

The criteria set out for analysis were not all met for the Inversion task. The first criterion was that the children should, as a group, be performing above chance levels on the control items and this was found. The second criterion was that the scores on the control items should be skewed, at or near ceiling performance. This demonstrates that when the task requires no manipulation of information, it is straightforward and that all the children understood the task. This was also found. The third criterion established whether there were any significant differences in the number of correct responses obtained by the hearing and hearing impaired children. If the hearing children were falling behind on the control items, compared to the hearing impaired children, then this would suggest that there is something in the task design that favoured the hearing children. Differences were found: the hearing impaired obtained significantly fewer items correct on the control items and this weakens confidence in the construct validity of the inversion tasks. Differences between the groups may result from a lack of understanding of the instructions by the hearing impaired children.

The experimental items were designed with the aim of discriminating among the differing levels of understanding of time concepts held by the children. It was with this aim that the following prediction was made: it was predicted that the children would show a greater range of scores as they demonstrate varying levels of understanding of the concepts assessed in the experimental items requiring inversion. It was also predicted that that the hearing children would show a significantly higher number of items answered correctly than the hearing impaired children. It was not predicted that all the children perform at levels above chance as previously done so in the control items because it was not expected that all the hearing impaired children would fully comprehend concepts of time. However, this criterion was not met. There were no significant differences between the two groups. This, taken together with the results of the correlations with other time concept tasks and NFER(1), lead to serious doubts concerning the validity of the task. The hearing impaired children may nor have understood the task instructions, the predicted results were not obtained for the control or the experimental items. No further analysis will be carried out with the Inversion task.

Change task

A reduced set of items based of half the full set of items chosen at random was administered to both the hearing and hearing impaired children. No control items could be designed for the present task. Thus the initial analyses carried out on the previous tasks do not apply to the Change task.

There was a possibility that the scores of some of the hearing impaired children was inflated because they obtained a correct response by chance through guessing. To correct for this possibility the formula proposed by Kline (2000) was applied to the raw scores. Subsequent analyses were carried out with the corrected scores.

The distribution of scores obtained were tested for skewness to establish whether statistical tests that assume the normal distribution of data could be used to analyse performance on this task (Howitt & Cramer, 1997). As can be seen in figure 3.23 the distribution of the corrected Change scores appear to be skewed this was confirmed with analysis (z=-2.16; *p*=.05).

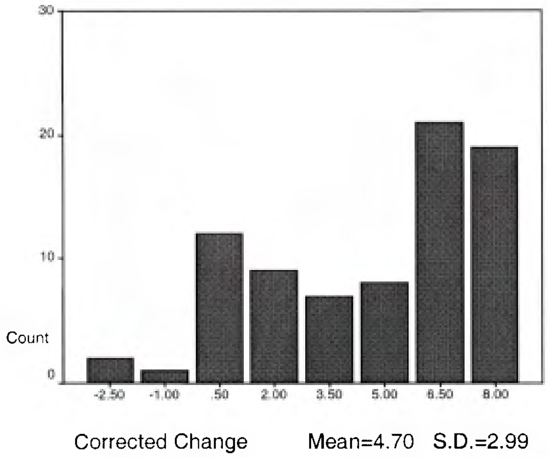


Figure 3.23 Distribution of scores in Change task for whole sample

The analysis examining the skewness of the distribution of the corrected Change scores for each group (figure 3.23) was also carried out. The distribution of the scores obtained by the hearing was significantly skewed (z=-3.62; *p*=.05). The distribution of the scores obtained by the hearing impaired children was not significantly skewed (z=0.95; *p*<.05).

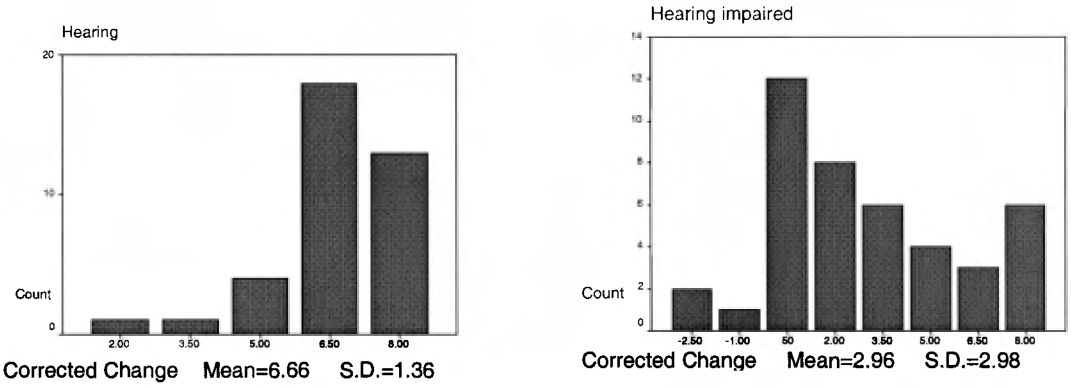


Figure 3.24 Distribution of Corrected Change scores by group

Some of the distributions observed were skewed, so statistical tests that do not assume normal distribution of data should be used in the following analyses.

It was predicted that, as with the previous experimental items, significant differences in the mean corrected Change scores would be found between the groups. The mean rank for the hearing children was 52.55 and for the hearing impaired children was 28.94. A Mann Whitney–U analysis of the mean rank of corrected scores was carried out and it was found that the hearing children obtained significantly higher scores that the hearing impaired children ($Z=-4.64$; $p<.001$).

The predictions were confirmed, the hearing impaired children were behind their hearing counterparts on the Change task. It remains to be seen whether the differential performance on the Change task explain mathematics attainment in hearing impaired children, this is explored in Chapter 4.

3.4.4.6 Discussion and conclusions

Three time concepts tasks were designed for the study and so assessments for their reliability and validity had to be assessed before proceeding with statistical analysis. Analysis of the Place-holders task revealed that this measure was reliable and valid for both the hearing and hearing impaired children. The Change task appears to be a valid measure for the hearing impaired children but not for the hearing children. This may reflect an aspect of the linguistic delay that hearing impaired children experience as a consequence of their impairment. Because the present study was interested in predicting the mathematics attainment of the hearing impaired children this measure was retained. Further investigation of the reliability of the tasks are presented in the following chapter with the full set of items administered to the hearing impaired children. The reliability and validity of the Inversion task was not fully supported for either the hearing or the hearing impaired children. Modifications to the task should be carried out if the concept of inversion is to be investigated further. No further analysis will be carried out with the Inversion task.

When comparisons were made between the hearing and hearing impaired children on the tasks it was predicted that the hearing impaired children would obtained lower scores on the experimental items of the tasks. This was supported for the Place-holder and Change tasks. There were significant differences between the two groups with the hearing children obtaining higher scores. The first criterion of lower performance by the hearing impaired children was fulfilled on these tasks. It remains to be seen whether this lower performance predicts the lower mathematical scores obtained by the hearing impaired children. This will explored in the following chapter.

3.4.5 Language measures

3.4.5.1 Reading comprehension

Following the published procedure it was possible to convert the raw scores obtained in the MIRA reading comprehension task to standardised scores. However, many of the hearing impaired children taking part in this study obtained scores that were too low to be standardised following the published norms. This result reflects the lower linguistic levels found in the present sample. To examine the distribution of scores, the raw scores were used. The maximum score was possible was 11. The mean raw score obtained was 2.93 (*S.D.*=3.04). Only three children successfully completed the whole task and obtained a maximum score. Nine children were unable to answer any of the comprehension questions correctly. Nine children could only obtain one correct answer. Seven children obtained 3 correct answers.

This indicates that the distribution of the scores on the MIRA was essentially dichotomous with the majority of the children taking part in the study with very low linguistic ability and a small number of children that outperform all of these children. In other words the distribution of the data was significantly skewed (z=3.93; p=0.05). It is unsurprising that this task was very difficult for the majority of the children to perform.

Performance on this task satisfies the first criterion for the study, it remains to be seen whether the task is a significant predictor of mathematics attainment. This is presented in Chapter 4.

3.4.5.2 Receptive language tasks (CELF-R)

Two sub-tests were administered from the CELF-R battery of assessments, the Oral Directions task and the Sentence Structure task. The tasks were included in the third testing occasion because the results of the MIRA from the first testing had been so poor. These tasks were administered during the last academic term so only 41 of the original 42 children were administered this assessment.

In the Oral Directions task the maximum possible score was 22. The mean raw score was 5.39 (*S.D.*=4.67). Two children failed to give a correct answer to any of the items administered, thus obtaining a score of zero. The highest score obtained was 19 and was achieved by only one child. Ten of the children obtained 2 correct answers.

In the Sentence Structure task the maximum possible score was 26. The mean number of items answered correctly was 16.70 (*S.D.* =3.84). The minimum number of correct responses was 9 and the maximum was 25.

The raw scores could be converted to standardised scores for each sub-test. These standardised scores took the age of the child into account. In this way it was possible to compare the performance of the children in the present sample to hearing children of the same age on which the norms of the task were based. When the raw scores were converted to standardised scores on the basis of age, the mean standardised score for the Oral Directions task was 4.59 and the mean score for the Sentence Structure task was 6.02. The mean standardised score for the norm sample for both of the tasks was 10. This indicates that the present populations performed below the norms for their age group in both of the receptive language tasks.

3.4.5.3 Summary

As expected the hearing impaired children performed below the norms based on hearing children for both types of assessments, the reading comprehension and the receptive language assessment. This fulfils the first criterion of lower linguistic performance by the hearing impaired children. The predictive study examines whether this explains the lower performance of hearing impaired in mathematics.

3.4.6 Summary of the results

The hearing impaired children obtained lower scores than the hearing children taking part in the study on all the measures administered, except the Inversion task. Thus, the first criterion was met for all of these measures. It was therefore concluded that these measures could be used in the predictive analyses in the following study.

4. Predictive Study

4.1 Chapter organisation

The present chapter examines the relation between the various explanatory variables and mathematics scores longitudinally. The purpose of the design was to predict the mathematics scores obtained by the hearing impaired children over three different time periods using the scores on the cognitive, numerical and linguistic tasks assessed mainly during the first testing session. The relations were explored using regression analyses.

The chapter is organised in three sections. Initially, the demographic variables are examined to establish whether they are associated with performance in mathematics. Any demographic variables that are associated with mathematics must be controlled for in later analyses. The second section asks whether the cognitive and linguistic variables explored in the comparative study *explain* mathematics attainment. The concurrent relations between the explanatory measures and the mathematics tests, all administered simultaneously, are examined using regression analysis. This analysis reveals the strength of the relations between the explanatory and response variables. The third section asks whether the same cognitive and linguistic variables *predict* mathematics attainment. This is examined by analysing the relations between the explanatory variables, administered at time 1, and the maths assessments, administered at times 2 and 3. Cognitive and linguistic measures that predict attainment longitudinally can be considered plausible causal explanations for the poor performance of hearing impaired children in maths in comparison to their hearing peers.

4.2 Method

4.2.1 Subjects

The hearing impaired children who participated in the comparison study also participated in the longitudinal study and were tested on three separate occasions, once in each term of the academic year 1997/1998. During the Spring term one child was absent from school due to illness. During the last testing session a different child was absent because she had moved schools. The tasks administered are described in the previous chapter.

4.2.2 Instruments

4.2.2.1 Mathematics Assessments

i. NFER–Nelson 7-11 test series

The appropriate assessments for 8- and 9-year old children were administered to the children taking part in the study during the Autumn tern 1997 and again during the Summer term 1998. The procedure is described in section 3.2.2.1 in the previous chapter.

ii. The Basic Number Test Series

The second assessment was the Basic Number Test series, which consisted of the Basic Number Screening Test (Gillham & Hesse, 1996) and the Basic Number Diagnostic Test (Gillham, 1996). These were administered to the hearing impaired children in the Spring term. This test series was also chosen because the two different tests covered a mathematical ability range from 5-years to 12-years. Although the two tests are different, they have been designed to be comparable and compatible, in addition, the raw scores can be converted to standardised 'maths ages'. Items included in the assessment include: counting and writing numbers, addition and subtraction in the 'Diagnostic test'; and the four operations, identification of fractions and number patterns in the 'Screening test'.

Procedure

The tests were administered individually and in the mode of communication most appropriate to the child. There are two forms of the Basic Number test. The Diagnostic test is designed to assess those children with a mathematical ability ranging from the ages of 5 years to 7 years. The Basic Number Screening test is designed to assess those children with an ability range of 7 years to 12 years. The test administered to each child was chosen on the basis of the child's performance in the

NFER-Nelson test and upon consultation with the teachers. The child's raw score in the test was converted to a 'number age' according to the test manual. All the children obtained a number age and no extrapolation was required.

4.2.2.2 Child Information Sheet

The main purpose of the child information sheet was to obtain background information about the hearing impaired children. Information collected included the audiological history of the children such as the aided and unaided hearing loss, and cause of hearing loss. The information collected provided the data required for examining the relation between the demographic variables and performance in the standardised mathematics assessments.

Procedure

A copy of the Child Information sheet is included in Appendix A, which was designed by the researcher. The forms were completed by obtaining permission to look at each child's school records and upon consultation with the teachers. The amount of audiological information provided about each child varied from school to school. In many cases the schools had been sent incomplete records by the child's audiologist, for example the child's age when diagnosed was only available for 23 children. The three most common cases of incomplete information were levels of aided and unaided hearing loss, and the cause of hearing loss. Unaided levels of hearing loss were assessed on the basis of the most recent audiogram. If no audiogram for unaided hearing losses was available, the audiologists' classification of the child's hearing loss (e.g. 'severe' or 'mild') was noted; this was to avoid missing data. Audiograms of aided hearing losses were also noted, these were available for 29 children. The cause of hearing impairment was noted if it was mentioned specifically. If no mention was made of the cause, then the child was classified as having 'no known cause' of hearing loss.

4.2.2.3 WISC-III^{UK} Performance scale

The aim of assessing the non-verbal intelligence of the children taking part in the study was so that intelligence could be controlled for in the longitudinal analysis. A measure that had previously been used in studies with hearing impaired participants was desirable. The administration procedure is described in chapter 3 section 3.2.3.1.

4.2.2.4 Language measures

i. Reading comprehension

The Individual Reading Analysis (MIRA) was administered to the children during the Autumn term 1997. The administration procedure is described in section 3.2.3.2 in the previous chapter.

ii. Receptive language assessment

Two sub-tests from the “Clinical Evaluation of Language Fundamentals – Revised (CELF-R)” (Semel, Wiig & Secord, 1987) were administered to the children during the Summer term 1998 because the was a floor effect in the reading comprehension scale of the MIRA. Section 3.2.3.3 in the previous chapter describes the administration procedure and the modifications made to the task.

4.2.2.5 Number processing skill

The memory scan test was administered to the children taking part in the study. Measures of memory capacity and number processing speed were obtained from the task. Section 3.2.2.2 describes the procedure of the task.

4.2.2.6 Mental operations involving time concepts

The full range of 64 questions assessing the mental operations involving time concepts were administered to the hearing impaired children. The administration procedure is described in section 3.2.2.3.

4.2.2.7 Counting tasks

The hearing impaired children taking part in this study were asked to count forwards to fifty and backwards from twenty. This task was only administered to hearing impaired children because it was expected that hearing children with no additional difficulties in a mainstream classroom would all know how to count to fifty. However, the same assumption could not be made of the hearing impaired children taking part in the study. Research has shown that learning the number string can take longer for the signing deaf child (Secada, 1984). It can also be difficult for the oral deaf child, for example confusions between numbers that sound similar have been observed by oral hearing children such as jumping from the numbers 18, 81, 82, etc. when counting (Nunes and Moreno, 1998).

Procedure

The hearing impaired children were asked to count up to their 'highest' number. The children were stopped at fifty if they were able to count this far. The same children were then asked to count backwards from the numbers five, ten and twenty. If the child had not understood the term 'counting backwards', then an example of counting backwards from three was given. The researcher would demonstrate by saying the numbers while using gesture or sign. The researcher then asked the child to count backwards together with the researcher. Finally the researcher asked the child to count backwards by themselves. After it was ensured that the child had understood the task, the rest of the counting backwards task was administered. This task was administered in a fixed order. If the child failed in an attempt to count backwards from any particular number they were not asked to count backwards from a higher number.

4.2.2.8 Additive Composition of number

The Shop Task was administered as a measure of understanding of the additive composition of number. The administration procedure is described in the previous chapter, section 3.2.2.4.

4.3 Results

The results are presented in four sections. Firstly, the performance of the outcome measures is described. The previous chapter described the scores obtained on the mathematics assessment administered during time 1 (NFER(1)) in section 3.3.1.1. The results of the mathematics assessments administered at time 2 and at time 3 are presented in the following section. Secondly, the relations between the mathematics attainment and demographic information and variables associated with hearing impairment are analysed and presented. Thirdly, the concurrent relations between the predictor variables administered at the same time as the mathematics assessments are presented. Lastly, longitudinal relations between the predictor tasks administered at time 1 and the mathematics assessments administered at times 2 and 3 are presented.

4.3.1 Description of the outcome measures

4.3.1.1 Testing session 2 - Basic Number test Series ('Number Age')

This assessment was only administered to the hearing impaired children. The raw scores obtained were converted to number ages. One boy was ill during the second testing session, so the following number ages are based on 41 subjects. The mean number age was 7 years and 3 months (mean=87.20 months, *S.D.* 13.36 months). The range of the number ages was between 63 and 120 months. The equivalent chronological ages at the same period of testing was 8 years and 4 months (mean=100.85 months, *S.D.*=6.99 months). The minimum chronological age was 90 months and the maximum was 113 months. The difference between the mean number age and mean chronological age was 13.65 months. In other words, the number age of the children in the present sample was, on average, a year and one month behind their chronological age. The range of difference was from -13 months to 32 months: where the number age was 1 year and 1 month greater than the chronological age, to where the number age was 2 years and 8 months less than the chronological age. Figure 4.1 shows the distribution of scores obtained in the Basic Number test series.

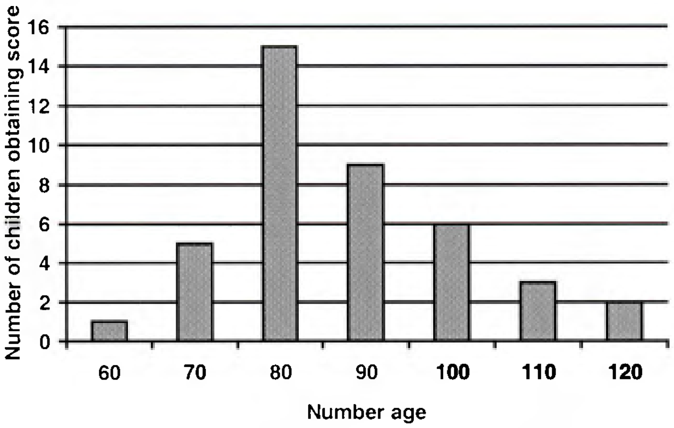


Figure 4.1 – Distribution of scores in the Basic Number assessments (n=41)

The distribution of the scores was examined to see if it was significantly skewed Howitt & Cramer, 1997). The z-score was 1, which indicates that the data were not significantly skewed.

4.3.1.2 Testing session 3 - ('NFER (3)')

The same NFER-Nelson assessment administered to the hearing impaired children during the Autumn term was administered again during the Summer term. When the raw scores were converted to a standardised score following the published procedure, 28 of the 41 children taking the test obtained a raw score high enough to be converted. The mean standardised score obtained following the published procedures was 85.75. In other words 13 children obtained scores that were 2 standard deviations below the published means.

The remaining standardised scores were extrapolated from the raw scores, as they were for the first administration. The mean standardised score for all the children after the extrapolated scores were calculated was 79.80 (*S.D.*=13.56). The range of scores was from 65 to 122. Figure 4.2 shows the distribution of scores.

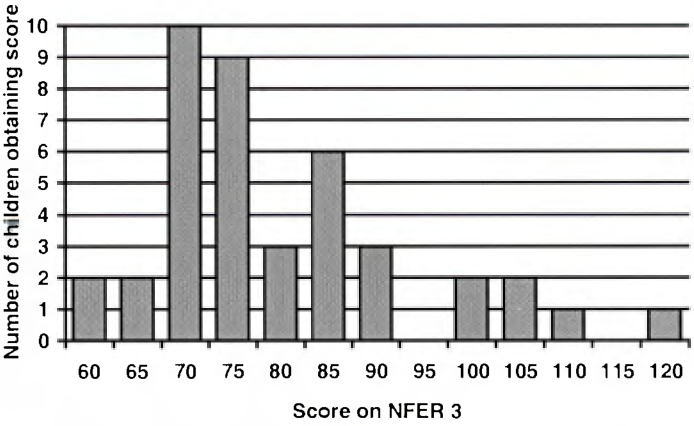


Figure 4.2 – Distribution of scores in NFER (3) extrapolated scores included (n=41)

The distribution of the scores was examined to see if it was significantly skewed Howitt & Cramer, 1997). The z-score was 2.43, which indicates that the data were significantly skewed.

For the purpose of analysis, the scores were normalised by taking the natural logarithm of the variable (Wright, 1997). This was carried out so statistical tests that assume normally distributed data could be used to analyse the mathematics scores. The standardised scores are presented in the tables for ease of reading and for comparison with later assessments. However, the statistical results reported are based on analysis with the normalised data.

Comparison between performances at times 1 and 3

The purpose of the present analysis was to establish whether the mathematics assessments were reliable measures for use with hearing impaired children. It was predicted that the scores obtained on the two administration of the NFER-Nelson assessment should be significantly correlated.

The mean scores obtained in the second administration of the NFER test was not significantly different from the first administration of the NFER test (paired t-test -t (40)=1.20; *p* (2-tailed)=0.22). This suggests that there was no significant improvement in mathematics attainment over the school year.

The standardised scores were compared directly for each child to examine the pattern of performance from time 1 to time 3. Figure 4.3 shows a scatter graph of the two standardised scores. The correlation for this relation was *r*=.83 (*p*<.001). The diagonal line represents the same standardised score at times 1 and 3. The points below the diagonal line show scores of children whose standardised scores were lower at time 3 than time 1. 14 children obtained lower standardised scores at time 3 than at time 1.

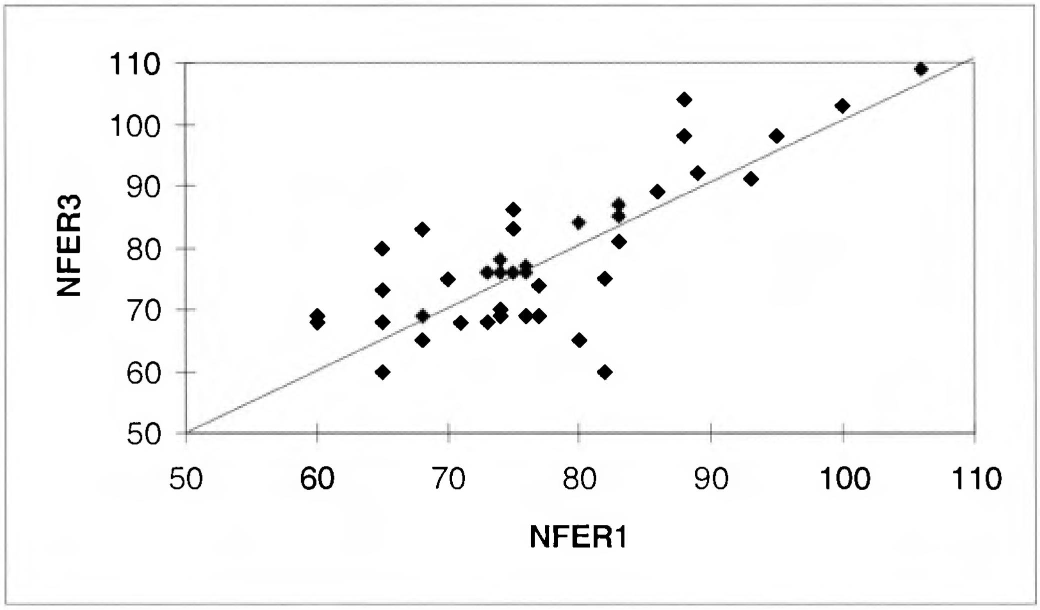


Figure 4.3 Scattergraph showing standardised scores obtained by each child at times 1 and 3

It was possible to compare the raw scores obtained by each child taking part in the study. This was to examine whether the lower standardised scores at time 3 were obtained as a direct result of answering fewer test items correctly. The following scatter graph shows the raw scores obtained at time 1 plotted against the raw scores obtained at time 3. Again the diagonal represents a score that was the same at times 1 and 3. Points below the line indicate that the raw score at time 3 was lower than the raw score at time 1. The scores were positively and significantly correlated (ρ=.71; *p*<.001).

6 children obtained a lower raw score at time 3 than time 1. Examination of the protocols revealed that two of these children had spent an extended time out of

school because they had been in hospital. The questions answered correctly at time 1 in all the protocols were questions that required a choice of (usually) four answers. This allowed for obtaining the correct answer by chance. At time 1 the children answered correctly by choosing the correct choice. At time 3, these children answered incorrectly by choosing an alternative choice.

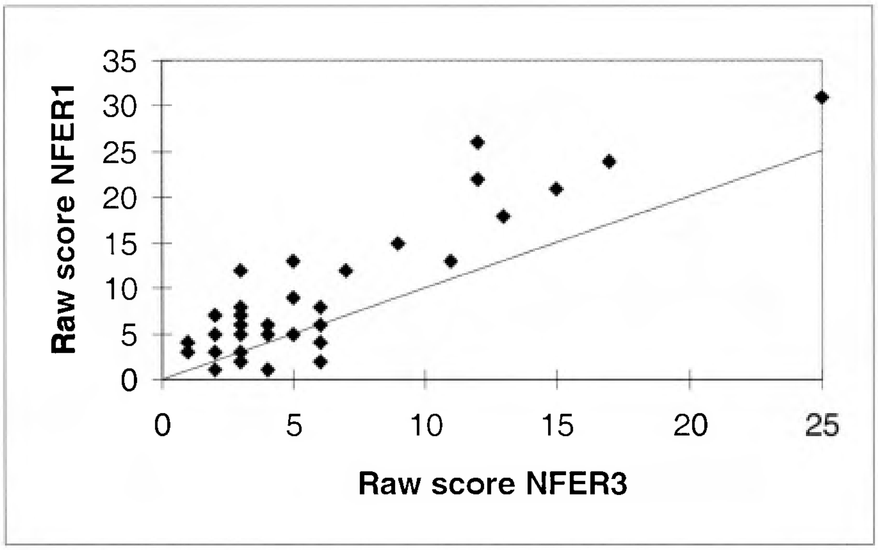


Figure 4.4 Scattergraph showing raw scores obtained in NFER (1) and NFER (3)

The difference in the number of children obtaining lower standardised scores and raw scores at time 3 suggests that it was possible to improve in real terms (the raw score) but that this was not always reflected in their standardised scores. If one is tested twice, as these children were, then an improvement in raw score is necessary to obtain the same standardised score at time 2. However, these children who obtained more correct answers at time 2 did not improve at the same rate as the hearing children on which the norms were based. This suggests that although the majority of the hearing impaired children in this study improved in real terms over an academic year, this improvement is not observed when comparing to the test norms. The highly significant correlations indicate that the mathematics measures were valid for use with this group of hearing impaired children.

4.4 Do the demographic variables explain mathematics attainment in a group of hearing impaired children?

The purpose of the following section is to establish whether performance in the standardised mathematics assessments can be explained by demographic variables factors associated with hearing impairment. The general hypothesis for the present section is that the demographic variables will explain little about the mathematics performance of the present group of children. Each demographic variable will be examined individually and following this, those variables that are found to be associated with mathematics achievement are analysed in a regression equation. Previous research (e.g. Wood *et al.*, 1984) has found a weak relation between specific demographic variables such as degree of hearing loss and gender, and mathematics performance in hearing impaired subjects. Firstly, for ease of reading, general demographic variables not specifically associated with hearing impairment are presented. Following this, demographic variables associated with hearing impairment are examined.

4.4.1 General demographic variables

4.4.1.1 Age

One would not expect a relation between the standardised maths scores obtained in the NFER-Nelson tests and age in this study because the standardised scores have been designed to take age into account. The child achieving average attainment levels for their age will obtain a score of around 100 at whatever age the test is taken.

The correlation between the NFER(1) standardised score and age (in months) was r=.41, p=.007. This is a positive correlation showing that the older children achieve higher standardised scores in the maths test.

The same relation was examined by comparing the means obtained by each year group. The mean standardised test score obtained by the children in year 3 was 72.77 (*S.D.*=6.21). The mean score obtained by year 4 was 84.40 (*S.D.*=13.24). A t-test analysis for independent means revealed that the means for the two groups was statistically different (t (26.41)= -3.59, p=.001).

As noted in the previous chapter, these results are not in the direction expected. There is an improvement of score with age and could indicate either that the mathematical ability of these hearing impaired children improves with age indicating a 'catching up' effect, or it could be an aspect of the group of children taking part in this study. It may have been, for example, that the children in the two year groups differed in levels of intelligence. A t-test analysis of WISC scores by year group examined this possibility. The mean WISC score for the year 3 children was 81.95 and the mean WISC score for the year 4 children was 90.40. Even though the year 4 children obtained a higher WISC score the difference was not significant (t(40)=-1.76; p=.09), so this idea was not supported. Nunes and Moreno (1998b) administered the same assessment to hearing impaired children and found no effect of age, so the implementation of the NFER-Nelson standardised scores as the outcome measures was maintained.

In the Basic Number Tests the standard score was a number age. One would expect a positive correlation between the chronological and number ages. As children get older, their competence in number assessments should increase. This was found (r=.55, p<.001).

Regression analyses with age as the explanatory variable and maths scores as the outcome measures. With NFER(1) as the outcome measure and age in months at time as the explanatory variable explained 17% of the variance the equation is Y' = 0.004 + (1.53X) where X is the individual's age and Y' is the best prediction of their mathematics score. With Number Age as the outcome measure and age in months at time 2 as the explanatory variable, the equation explained 30% of the variance. The equation was Y' = -18.05 + (1.04X) where X is the individual's age and Y' is the best prediction of their mathematics score. With NFER (3) as the outcome measure and age in months at time 3 as the explanatory variable, the equation explained 24% of the variance. The equation was Y' = 0.005 + (1.53X) where X is the individual's age and Y' is the best prediction of their mathematics score. The three equations were significant. To control for the association of standardised maths scores with age, the predictive analyses in the following sections will control for age.

4.4.1.2 Gender

Research with hearing children (e.g. Benbow & Stanley, 1980, 1983; Hyde, Fenema & Lamon, 1990) has shown that boys achieve higher mathematics scores than girls. An examination of the standardised results by gender in the present study can investigate whether the same pattern of performance is evident in the hearing impaired population.

Table 4.1 Means of standardised test scores by gender

Gender	NFER(1)	Basic Number Age	NFER(3)
Boys	80.22	87.14	80.96
	(*S.D.* 13.66)	(*S.D.*=14.18)	(*S.D.*=15.24)
	(n=23)	(n=22)	(n=23)
Girls	76.00	87.26	78.11
	(*S.D.*=8.39)	(*S.D.*=12.73)	(*S.D.*=11.87)
	(n=19)	(n=19)	(n=18)

T-test analyses for independent samples for each of the tests showed that, although the mean scores for the boys were higher, these differences were not significant (NFER(1) t (40)= -1.11, *p*=.27; Number age t (39)= 0.03, *p*=.98; NFER (3) t (39)=-0.67, *p*=.50). The summary table is included in Appendix C. The following analyses will therefore not control for gender.

4.4.1.3 School

One would not expect to find a relation between the scores obtained in the maths test and the schools the children are attending if they are all providing a similar curriculum for all the children.

Three one-way analysis of variance (with post-hoc analysis) of the standardised scores by schools revealed no differences between the schools (NFER(1) F(6, 35)=0.49; *p*=.81; Number Age F(6,34)=0.92; *p*=.49; NFER (3) F(6,34)=0.99; *p*=.45). The summary table is included in Appendix C.

There were no significant differences between schools in the present study. As a result, following analyses will not control for school placement.

4.4.2 Demographic variables associated with hearing impairment

4.4.2.1 Levels of hearing loss

Previous studies have found a weak relation between the levels of hearing impairment and mathematics attainment. If hearing impairment were a cause of the low achievement levels in mathematics, one would expect that more severe hearing losses would be associated with lower attainment scores. To investigate this relation in the present study, the standardised scores on the mathematics assessment were correlated with unaided hearing losses. Meadow (1978) has suggested that the levels of hearing loss with hearing aids may provide a more useful measure of children's hearing level. For this reason this information was also correlated with maths score. This information was only available for 29 of the children

Table 4.2 Correlations between levels of hearing loss and scores obtained in standardised maths tests

Type of hearing loss	NFER-Nelson 1.	Basic Number Age	NFER-Nelson 2.
Unaided loss	*r*=-.25 (*p*=.11) (n=42)	*r*=-.20 (*p*=.21) (n=41)	*r*=-.25 (*p*=.11) (n=41)
Aided loss	*r*=-.19 (*p*=.32) (n=29)	*r*=-.15 (*p*=.44) (n=28)	*r*=-.21 (*p*=.27) (n=28)

Although the correlations were in the direction expected, none of the correlations were significant. This was the case for the correlations with unaided and aided hearing loss. The following analyses will not, therefore, control for degree of unaided or aided hearing loss.

4.4.2.2 Age of child at diagnosis

It was hypothesised that the age at which the children were identified as hearing impaired would be an important variable. This would indicate when the child first received medical attention for their hearing loss, such as the provision of hearing aids and speech and language therapy. This information was only available for 23 of the children taking part in the study. Five children had become ill after illnesses. The information about one child was not complete had not been included in the previous analysis. The four remaining children became deaf after birth after becoming ill with meningitis and so were excluded from the analysis. One would expect lower mathematics scores to be obtained by those children who were diagnosed and received medical attention later, assuming that they had been born with a hearing impairment. This would result in a negative correlation.

The correlation between the NFER-Nelson (1) score and age at diagnosis was r=- .52 (p=.02; n=19). The correlation between Number age and age at diagnosis was r=-.46 (p=.06; n=18). The correlation between NFER (3) and the child's age at diagnosis was r=-.24 (p =.33; n=19).

The correlations were in the expected direction, only the correlation between age at diagnosis and NFER (1) was significant. The correlations for the Number age and NFER (3) tests were not significant. Because this information was only available for a small number of children this variable cannot be controlled for in the present study. It may also be that the age at diagnosis may also be confounded with other factors. For instance, although children that were identified as becoming deafened were excluded for the analysis, it may be that other children also became deaf through unknown, and unidentified, reasons may also be included in this sample. Information from more children, and from more reliable sources, would have to be collected to investigate this relation further. This could be included as a variable in future studies.

4.4.2.3 Cause of hearing impairment

Twenty children in the study had unknown causes of hearing impairment. Ten children had hereditary causes of hearing impairment and two children had causes of hearing impairments that were associated with a chromosomal syndrome. Five children experienced difficulties at birth and as a consequence were hearing impaired. Five children were hearing impaired after serious illnesses, four with meningitis and one with rubella, which are all associated with addition learning difficulties. The information about the child who became ill with rubella was incomplete. It was not known how old the child was when she became ill, which is why she was excluded in the analysis in the previous section.

The causes of hearing impairment were classified into two groups; those causes associated with possible neurological or learning difficulties and those not associated with additional difficulties. The children with hereditary or chromosomal causes were placed in one group. The children with hearing impairment as a result of difficulties at birth or illnesses were classified in another group. The mean standardised scores obtained were compared using a t-test analysis for these two groups.

Table 4.3 Mean standardised maths scores by cause of hearing loss

	NFER-Nelson 1.	**Basic Number Age**	**NFER-Nelson 2.**
With no associated difficulties	82.17 (S.D = 14.86) n = 12	90.00 (S.D = 13.42) n = 11	85.00 (S.D = 15.66) n = 12
With possible associated difficulties	71.20 (S.D = 7.76) n = 10	82.20 (S.D = 11.93) n = 10	75.30 (S.D = 12.15) n = 10

The children with no associated difficulties obtained higher standardised scores. Analyses of the means obtained by both groups were compared for each test by carrying out a t-test to examine whether there were significant differences between them. One significant difference was found between the two groups (NFER(1) t(20)=2.04; p=0.05: Number Age t (19)=1.40; p=0.18: NFER(3) t(20)=1.59; p=0.13).

It is possible that the study failed to find a consistent significant result because the number of observations in each category was small. This analysis would have to be repeated with a larger number of children in each category in future studies. Because the numbers are small in the present study, this measure will not be controlled for in the rest of the analyses.

4.4.2.4 Family history of hearing loss

The children were classified into two groups, those with a history of hearing impairment in the family and those with no history of hearing impairment in the family. The mean scores obtained in the tests can be seen in the following table. It was hypothesised that those children with previous family history of hearing loss would obtain significantly higher means than the children with no previous history of hearing impairment. This could be for two reasons. Firstly because the children with previous history do not have a cause of hearing impairment associated with additional learning difficulties. Secondly, children born into families with a previous history of hearing impairment could be in an advantageous position in comparison with the other children because their communication requirements are being met from an early age. One child was adopted from an orphanage and so no information was available.

Table 4.4 Mean standardised maths scores by previous family history of hearing impairment

	NFER-Nelson 1.	**Basic Number Age**	**NFER-Nelson 2.**
With family history	79.27 (*S.D.*=14.85) (n=11)	87.20 (*S.D.*=13.53) (n=10)	82.90 (*S.D.*=15.96) (n=10)
No family history	78.30 (*S.D.*=10.56) (n=30)	87.90 (*S.D.*=13.16) (n=30)	79.13 (*S.D.*=13.09) (n=30)

T-test analyses for independent samples revealed no significant differences in any of the tests between children with or without previous history of hearing impairment. (NFER (1) t(39)= -0.05, p=.96; Number Age: t (38)=0.14, p=.89; NFER (3) t(38)=-0.66, p=.52).

The hypothesis was not supported, no significant differences were found between the two groups. For this reason family history of hearing impairment will not be controlled for in future analysis.

4.4.3 Linguistic variables

4.4.3.1 Signing environment

The children were classified into three groups based on their reliance on sign language for communicating. No distinction was made between the use of BSL or SSE because the number of children in each group would have been too small for statistical analysis. A child classified in the 'no reliance on sign at all' group was an oral child with no apparent knowledge of sign. A child in the 'some reliance on sign' group used sign occasionally and the school they attended provided additional cues and information to varying degrees. The final group of children placed in the 'relies on sign' category used sign language as the main mode of communication, either SSE or BSL. The following table presents the means obtained by each group in the different standardised tests.

Table 4.5 Mean standardised maths scores by reliance on sign

Use of sign	NFER-Nelson 1.	Basic Number Age	NFER-Nelson 2.
No sign	80.46 (*S.D.*=16.07) (n=13)	88.85 (*S.D.*=18.02) (n=13)	81.46 (*S.D.*=18.64) (n=13)
Some sign	77.62 (*S.D.*=9.72) (n=21)	86.65 (*S.D.*=11.55) (n=20)	79.86 (*S.D.*=11.82) (n=21)
Relies on sign	76.63 (*S.D.*=8.25) (n=8)	85.88 (*S.D.*=9.61) (n=8)	76.00 8.98 (n=7)

Analysis of the means of these three groups with one-way ANOVA revealed that there were no differences in the mean scores obtained by use of sign. (NFER(1): F(2,39)=0.29, *p*=.75; Number Age: F (2, 38)=0.15, *p*=.86; NFER(3): F(2,38)=0.35, *p*=.71). Because the three groups differed in size, a distribution-free analysis was also used to examine this relation. Kruskal-Wallis one way analysis of variance also found no significant differences between the three groups for each of the assessments, the following values are all corrected for ties (NFER(1) K-W (2)=0.04, *p*=.98; Number Age K-W (2)=0.03, *p*=.99; NFER(3) K-W(2)=0.65, *p*=.72). The summary table is included in Appendix C. The hypothesis that signing status predicts performance in standardised maths tests was not supported by the analysis and linguistic background will not be included in further analyses.

4.4.3.2 English as a first language

The children were then classified as being members of families either having or not having English as a first language. The means of these two groups were compared and analysed with a t-test analysis for independent samples.

It was hypothesised that those children with English as their first language would be at an advantage over their peers who have to deal with more than one language as well as their hearing loss.

Table 4.6 Means of standardised tests by first language used at the child's home

First language	NFER-Nelson 1.	Basic Number Age	NFER-Nelson 2.
English first Language	78.17 (*S.D.*=13.57) (n=23)	87.87 (*S.D.*=13.84) (n=23)	78.87 (*S.D.*=14.92) (n=23)
English not first Language	78.47 (*S.D.*=9.14) (n=19)	86.33 (*S.D.*=13.04) (n=18)	80.78 (*S.D.*=12.50) (n=18)

T-test analysis for independent samples revealed no significant differences between the means obtained by the two groups (NFER (1) t (40)=0.25, *p*=.80: Number Age t (39)= -0.36, *p*=.72: NFER (3) t(39)=055, *p*=.59). The hypothesis that those children with English as a first language have an advantage over the other children was not supported. This will not be included in further analyses.

4.4.3.3 Signing at home

The children were classified as having exposure to sign at home or not. The distinction between SSE and BSL was not made because, although some parents were taking BSL courses, their method of signed communication at home was not known. It was hypothesised that the children who receive additional communication support at home would obtain higher scores on the mathematics tests.

Table 4.7 Mean standardised test score by use of sign at home

Use of sign at home	**NFER-Nelson 1.**	**Basic Number Age**	**NFER-Nelson 2.**
Sign at home	77.68 (*S.D.*=8.01) (n=19)	84.17 (*S.D.*=8.07) (n=18)	75.72 (*S.D.*=8.98) (n=18)
No sign at home	78.83 (*S.D.*=14.12) (n=23)	89.57 (*S.D.*=16.15) (n=23)	82.83 (*S.D.*=16.11) (n=23)

T-test analyses for independent samples revealed no significant differences in the means obtained by the two groups (NFER (1) t (38.11)=0.24, p=.81; Number Age t (33.82)=1.40, p=.17; NFER (3) t(36.96)=1.68, p=.10). The hypothesis that signing at home is associated to mathematical attainment was not supported. If the extent of signing at home could be ascertained, perhaps the amount of signed communication at home may prove to be related to mathematical attainment. This could be explored in future studies. The present study will not control for exposure to sign language at home.

4.4.3.4 Summary

This section examined the relation between the demographic variables and mathematical attainment in hearing impaired children. Previous literature found few significant relations between these variables. This study also found few significant relations between these variables. None of the demographic variables associated with hearing loss was significantly related to any of the mathematics assessments. Age was the only variable to yield a significant result. This was surprising in the case of the NFER-Nelson assessment because the standardised scores are supposed to take into account. As a consequence, the following analyses will control for age. The study confirms the need to go beyond demographic variables when attempting to explain the variance in mathematics attainment.

4.5 Concurrent analysis - Do the cognitive and linguistic variables *explain* mathematics performance?

This question was examined in the present section by analysing the relations between the measures administered at the same time. This principally concerned the relation between NFER (1) and the various explanatory variables administered at time 1. In addition to this, a language assessment was administered at time 3 so the relation between this and the mathematics test administered at the same time is also explored. The present section deals, then, with the strength of the relations between the various predictor variables and mathematics attainment. The direction of causality was not examined in the present section, this is addressed in section 4.5.

The relations between the variables were examined with correlations and regression analyses. Summary tables of the correlations are included for reference in the Appendix C.

The technique for the regression analyses implemented was fixed order regression equations with age in the first step and non-verbal IQ placed in the second step and the explanatory variable as the third step. This method was used because the variable of most interest in the analyses is the variable placed in the third step of the regression equation. The 'fixed order' method allows the researcher to partial out the effects of variables that must be controlled for because they have a significant association with mathematics. Once this has been achieved, the strength of the specific relations between mathematics score and variable of interest can be examined. Age was controlled for (partialled out) because it was significantly associated with standardised mathematics score and it is expected to also be associated with the cognitive and linguistic measures. Non-verbal IQ was placed in the second step of the equation as a control because it is associated with mathematics ability, and with the cognitive and linguistic measures. In this way it was possible to examine the significance of the explanatory variable after controlling for age and non-verbal IQ, thus asking the question - does performance in each cognitive and linguistic task show a specific relation with mathematics achievement?

The WISC performance IQ score of one child was over two standard deviations above the mean and he was an outlier. Because non-verbal IQ was being controlled for, the decision was made to exclude this child from the regression analyses. The remaining analyses were carried out with 41 children and in each case there were three explanatory variables. Green (1991) suggests a formula that assesses whether the ratio of subjects to variables is acceptable for a regression analysis. According to power analysis (Cohen, 1988), in a study with three predictors and a large effect size, the number of subjects required is 35. According to Green (1991) an adequate sample size in an analysis with three predictors and a large effect size is 31. Towards the end of this section analysis is carried out with four predictors. Under these criteria, Cohen (1988) calculates that a sample size of 39 is sufficient and Green suggests that a sample size of 35 is sufficient. The present study satisfies the criteria set out by the two authors.

With regards to the assumptions of the distribution of the predictor variables in multiple regression analysis, Moore and McCabe (1993) state, "It is important to note that the multiple regression *does not* require any of these distributions to be normal. Only the deviations of the responses *y* for their means are assumed to be normal" (Moore & McCabe, 1993; p. 693; authors' italics). The predictor variables can be in the form of categories, ordered categories or interval scores (Plewis, 1997). The distribution of the scores within each score or category does not have to be equal, the predictor variable can have a disproportionate or unequal number of cases in each subclass. The main assumption of regression analyses is that no heteroscedasticity can be seen in the data or in the residuals of the data (Plewis, 1997; Wright, 1997). This was checked for in each case by checking the 'residual plots' and the assumption was satisfied in each case. This is a scattergraph of the standardised residuals against the predicted value. This assessment is done 'by eye' and one should ensure that the distribution of the points should not show a pattern and not be uniform. These scattergraphs are included in the Appendix C together with the summary tables of the regression analyses.

It was seen in the scattergraphs that the main assumption of no heteroscedasticity was not violated. There were some scattergraphs that were 'borderline' and could raise some concern. These were for the equations with the response times to the memory task as the predictors and NFER(3) as the outcome measure. This indicates that the relation may not be linear. However, given the lack of significant results on these particular equations, these were not considered hazardous to the conclusions drawn in the study.

4.5.1 Examination of the predictor variables

Throughout the analyses each predictor variable is examined in turn. In each section the hypothesis is tested by examining the relation between the predictor variable and score in the mathematics test administered at the same time. For the hypothesis to be supported the predictor must be significantly correlated with the mathematics score and be a significant predictor of mathematics score above and beyond age and non-verbal IQ.

4.5.1.1 Memory capacity as the explanatory variable

It was hypothesised by Hitch *et al.* (1983) and Epstein *et al.* (1990) that the memory capacity scores are positively correlated with standardised mathematics scores and that they are a significant predictor of mathematical ability. According to this model, smaller memory capacities will directly influence ability to process number.

The correlation between NFER (1) scores and the memory capacity score was $r = .41$ ($p < .01$). This relation indicates that as memory capacity increases so do the NFER (1) scores. A fixed order multiple regression was carried out, table 4.8 summarises the results of the regression.

Table 4.8 Summary of fixed order multiple regression with NFER (1) standardised score as the outcome variable with age, non-verbal IQ and memory capacity as the predictor variables

Step	**Variable**	**R^2 change**	**B**	**SE B**	**β**
1	age at time 1	0.16 **	0.002	0.001	0.25
2	WISC	0.15 **	0.001	0.001	0.33
3 (n = 41)	Memory capacity	0.03 $^{n.s.}$	0.007	0.006	0.19

Significant F change: * $p < .05$, ** $p < .01$, *** $p < .001$, **** $p < .0001$, $^{n.s.}$ not significant

After controlling for age and intelligence, memory capacity did not explain a significant amount of variance in the regression analysis with NFER (1) score as the outcome variable. The results indicate that, although memory capacity and mathematics score are associated, memory capacity does not show a specific relation to performance in the standardised mathematics assessment.

4.5.1.2 Response times as the explanatory variable

Epstein *et al.* (1990) predicted that the response times to the correct responses in the memory scan task would predict mathematics performance. According to a causal model, the ability to process number quickly would lead to an improved mathematical ability. Thus, one would expect those children with quicker response times in the memory scan task to obtain higher NFER (1) scores. This was examined directly in the present study.

Table 4.9 summarises the correlations between NFER (1) score and the response times for each task item. The task was divided into positive and negative probes, and stimulus set size. The correlations were all negative, indicating that those children with smaller response times (i.e. those who responded more quickly), obtained higher NFER (1) scores. All but three of the correlations were significant. The negative probe for SSS2 and the positive probes for SSS1 and SSS4 were not significant.

Table 4.9 Correlations between NFER (1) score and response times in memory scan task

Task	**SSS1**	**SSS2**	**SSS3**	**SSS4**	**SSS5**	**SSS6**
Negative probes						
r	-.35	-.25	-.33	-.36	-.51	-.38
p	.03	.12	.04	.02	.001	.02
n	41	40	40	40	38	39
Positive probes						
r	-.26	-.33	-.34	-.20	-.50	-.37
p	.10	.04	.03	.22	.001	.03
n	41	41	41	41	39	36

The hypothesis that quicker response times explain mathematics score was tested by examining the relations between each of the response scores and score in NFER (1). For the hypothesis to be supported the predictor must be negatively correlated and a significant predictor of mathematics score above and beyond non-verbal IQ.

Twelve fixed order multiple regressions were carried out to test the hypothesis that response time explains performance in standardised mathematics assessments. In each of the regressions the first and second step were age and WISC score, the third step was the response time in each of the conditions in the memory scan task. Table 4.10 summarises the results of the regression analyses. As can be seen in the table, only three of the response time variables added a significant amount of variance to the overall regression equation. These were the negative probes for the conditions SSS1 and SSS6, and the positive probe for SSS5.

The isolated significant results do not suffice to support the hypothesis. Although nine of the response variables were significantly correlated with mathematics score and three of the response time variables were significant predictors of mathematics score after controlling for age and non-verbal IQ, the pattern of results is not consistent.

The measures of memory capacity and the response scores on the memory task were, in general, significantly associated with the score obtained on the standardised mathematics test. However, further analysis revealed that, after controlling for age and IQ, performance on the memory task does not explain mathematics achievement.

Table 4.10 Summary of twelve fixed order regression analyses with NFER (1) as the outcome measure with age, non-verbal IQ and response times in the memory scan task as the predictor variables

Step	Variable	R^2 change	B	SE B	β
1†	Age	0.17 **	0.002	0.001	0.28
2†	WISC	0.15 **	0.001	0.001	0.38
Negative probes					
3 (n = 41)	SSS1	0.10 *	-0.008	0.003	-0.31
3 (n = 41)	SSS2	<0.01 $^{\text{n.s.}}$	-0.0001	0.003	-0.001
3 (n = 41)	SSS3	0.01 $^{\text{n.s.}}$	-0.003	0.004	-0.13
3 (n = 41)	SSS4	0.05 $^{\text{n.s.}}$	-0.01	0.007	-0.23
3 (n = 39)	SSS5	0.07 $^{\text{n.s.}}$	-0.01	0.006	-0.30
3 (n = 40)	SSS6	0.11 *	-0.01	0.004	-0.36
Positive probes					
3 (n = 42)	SSS1	<0.01 $^{\text{n.s.}}$	-0.002	0.007	-0.05
3 (n = 42)	SSS2	0.02 $^{\text{n.s.}}$	-0.005	0.005	-0.14
3 (n = 42)	SSS3	0.05 $^{\text{n.s.}}$	-0.008	0.004	-0.32
3 (n = 42)	SSS4	<0.01 $^{\text{n.s.}}$	-0.0005	0.005	-0.02
3 (n = 40)	SSS5	0.11 *	-0.02	0.007	-0.36
3 (n = 37)	SSS6	<0.01 $^{\text{n.s.}}$	-0.004	0.008	-0.09

Significant F change: * $p < .05$, ** $p < .01$, *** $p < .001$, **** $p < .0001$, $^{\text{n.s.}}$ not significant

† Note: The values for the first and second step were taken from the regression analysis with the response time for the negative probes in SSS1 as the third step. The complete summary tables are included in the Appendix.

4.5.1.3 Language assessments as the explanatory variable

The following section examines whether better linguistic skills, as measured by standardised assessments, explain mathematical performance in a sample of hearing impaired children. According to the hypothesis, those children with better linguistic skills will also perform better in the mathematical assessments. Section 4.3.3 previously found no significant differences in mathematics attainment between children who used different modes in communication. For this reason, there will be no distinction between language communication modes in the present analysis.

The language assessments were administered in two testing sessions, the first and the last testing sessions. To explore the hypothesis that language ability explains performance in mathematics administered concurrently, the language assessments were examined with the maths assessment that was administered in the same testing period. The relation between the Individual Reading Analysis (MIRA) and NFER (1) is examined, and the relation between the two CELF-R assessments and NFER (3) is examined. During the analyses with the CELF-R assessments, the non-verbal WISC score was used in the second analyses as the second step despite having been administered at time 1. This was because the WISC score represents the standardised IQ score. It was expected that this would remain stable over the school year.

The correlations between the language assessments and the mathematical assessments were all significant. This shows that there is a relation between language ability and mathematical attainment. The correlation between the NFER (1) standardised score and the MIRA raw score was $\rho=.47$ ($p<.001$). The correlation between the raw score in the Oral Directions task of the CELF-R assessment and NFER (3) standardised score was $\rho=.60$ ($p<.001$). The correlation between the raw score in the Sentence Structure task of the CELF-R assessment and the NFER (3) standardised score was $\rho=.51$ ($p<.001$).

A series of fixed order multiple regression analyses was carried out. The results of the analyses are shown in tables 4.11, 4.12 and 4.13. In tables 4.12 and 4.13 the first step is age at the time of testing (age at 3) and the outcome variable is the mathematics assessments administered at time 3.

Table 4.11 Summary of fixed order multiple regression with NFER (1) standardised score as the outcome variable with age, non-verbal IQ and MIRA raw score as the predictor variables

Step	Variable	R^2 change	B	SE B	β
1	age at time 1	0.16 **	0.001	0.001	0.13
2	WISC	0.15 **	0.001	0.001	0.31
3 (n = 41)	MIRA raw score	0.11 **	0.008	0.003	0.39

Significant F change: * $p< .05$, ** $p< .01$, *** $p< .001$, **** $p< .0001$, $^{n.s.}$ not significant

Table 4.12 Summary of fixed order multiple regression with NFER (3) standardised score as the outcome variable with age, non-verbal IQ and CELF (OD) as the predictor variables

Step	Variable	R^2 change	B	SE B	β
1	age at time 3	0.24 **	0.002	0.001	0.26
2	WISC	0.16 **	0.001	0.001	0.18
3 (n = 40)	CELF-R (OD)	0.26 ****	0.009	0.002	0.54

Significant F change: * $p< .05$, ** $p< .01$, *** $p< .001$, **** $p< .0001$, $^{n.s.}$ not significant

Table 4.13 Summary of fixed order multiple regression with NFER (3) standardised score as the outcome variable with age, non-verbal IQ and CELF (SS) as the predictor variables

Step	Variable	R^2 change	B	SE B	β
1	age at time 3	0.24 **	0.002	0.001	0.27
2	WISC	0.16 **	0.001	0.001	0.33
3 (n = 40)	CELF-R (SS)	0.06 *	0.005	0.002	0.29

Significant F change: * $p< .05$, ** $p< .01$, *** $p< .001$, **** $p< .0001$, $^{n.s.}$ not significant

The overall results support the hypothesis; all three language assessments were significantly correlated with mathematics scores and added a significant amount of variance in the third step in the regression analyses. Linguistic ability, as measured by these tasks, was a significant predictor of mathematics attainment.

4.5.1.4 Understanding of the additive composition of number as the explanatory variable

The understanding of the additive composition of number was assessed with the Shop Task. The three categories of performance were those who demonstrated ‘no’ understanding, ‘some’ understanding and ‘good’ understanding of additive composition. It was hypothesised that understanding of additive composition would explain performance in standardised mathematics assessments.

The score in the Shop Task was significantly correlated with the standardised maths score ($\rho=.63$; $p<.001$). A fixed order multiple regression analysis with the Shop Task scores in categories as the third step was carried out. The results of the regression analysis are summarised in table 4.14. The Shop Task explained a significant amount of variance after controlling for age and WISC score.

Table 4.14 Summary of fixed order multiple regression with NFER (1) standardised score as the outcome variable with age, non-verbal IQ and Shop Task as the predictor variables

Step	Variable	**R^2 change**	B	SE B	β
1	age at time 1	0.16 **	0.001	0.001	0.10
2	WISC	0.15 **	0.001	0.001	0.21
3 (n = 41)	Shop Task	0.17**	0.03	0.009	0.51

Significant F change: * $p< .05$, ** $p< .01$, *** $p< .001$, **** $p< .0001$, $^{n.s.}$ not significant

The hypothesis was supported. The Shop Task was significantly correlated with NFER (1) score and it was a significant predictor of NFER (1) after controlling for age and non-verbal IQ. It could be argued, however, that the understanding of additive composition is a counting ability skill and nothing more. This issue was examined and is reported in the following section.

4.5.1.5 Counting ability as the explanatory variable

Two tasks were administered to assess counting ability in the present study. These were counting up to the highest number and counting backwards. When the children were counting up to the highest number they were stopped at 50 if they made no mistakes; 29 children were able to complete the task and count to fifty. Five children completed the task but made one mistake. Two children could only count to twenty-nine. Two children counted to twenty with no errors and two children counted to twelve with no errors.

The children were also asked to count backwards from 5, 10 and 20 in successive order. They were given a point for each successful trial. 27 children were able to complete the task and count backwards from twenty. 10 children were able to count backwards from five and ten, but not twenty. 1 child could only count backwards from five and 4 children were unable to count backwards.

This section examines whether counting ability can explain the score on a standardised maths assessment. If counting ability is significantly associated and predicts mathematical ability on the standardised assessments, then the relation between counting ability and additive composition will have to be explored further, because they may be measuring the same construct. Counting to the highest number was significantly correlated to maths score ($\rho=.36$, $p<.05$). Counting backwards was also significantly correlated with maths score ($\rho=.49$, $p=.001$). To examine the hypothesis that counting ability explains performance in mathematics, two fixed order multiple regressions were carried out. Counting ability and counting backwards were placed as the third step in each regression analysis. Age and WISC were placed in the first and second steps. Tables 4.15 and 4.16 summarise the results of the multiple regression analyses. Neither of the counting tasks explained a significant amount of variance in the regression equations after controlling for age and intelligence as measured by the performance scale of the WISC.

Table 4.15 Summary of fixed order multiple regression with NFER (1) standardised score as the outcome variable with age, non-verbal IQ and score on counting task as the predictor variables

Step	**Variable**	**R^2 change**	**B**	**SE B**	β
1	age at time 1	0.16 **	0.002	0.001	0.27
2	WISC	0.15 **	0.001	0.001	0.35
3 (n = 41)	Counting to highest	$0.01^{\text{n.s.}}$	0.001	0.001	0.13

Significant F change: * $p < .05$, ** $p < .01$, *** $p < .001$, **** $p < .0001$, $^{\text{n.s.}}$ not significant

Table 4.16 Summary of fixed order multiple regression with NFER (1) standardised score as the outcome variable and age, non-verbal IQ and score on counting backwards task as the predictor variables

Step	**Variable**	**R^2 change**	**B**	**SE B**	β
1	age at time 1	0.16 **	0.002	0.001	0.28
2	WISC	0.15 **	0.001	0.001	0.25
3 (n = 41)	Counting backwards	$0.05^{\text{n.s.}}$	0.02	0.009	0.27

Significant F change: * $p < .05$, ** $p < .01$, *** $p < .001$, **** $p < .0001$, $^{\text{n.s.}}$ not significant

The hypothesis that counting ability is specifically related to mathematics attainment was not supported. Although the two counting tasks were significantly correlated with mathematics score, neither task was a significant predictor of mathematics after controlling for age and IQ. Counting may be a significant predictor of mathematical attainment in a group of younger hearing impaired children who are not as competent at counting. The failure to find a significant result in the regression analyses in the present section suggests that additive composition is not merely a counting skill. It appears that the counting task and the Shop task measure different skills. No further analyses with this task will be carried out.

4.5.1.6 Understanding of time concepts as the explanatory variable

The understanding of time concepts was assessed using tasks developed for the present study. In the previous chapter (section 3.4.4) it was found that the hearing impaired children obtained significantly lower number of correct responses on two tasks assessing time concepts. The two tasks can be separated into two categories: the first assessed children's ability to identify the correct sequence of pictures based on sequential information using place-holders (P-HR); the second assessed the children's ability to identify the first picture in a story that involved a transformation ('Change'). These were taken as measures of ability to talk and reason about time. It was predicted that both these tasks would explain a significant amount of variance of mathematical attainment after controlling for age and non-verbal intelligence.

Because these tasks were developed for the study further examination of their construct validity is desirable. The analyses are presented in two sections: the first deals with the validity and reliability of the measures, and the second addresses the hypothesis that the measures predict mathematics scores after controlling for age and intelligence. The analysis in the first section is based on the raw scores obtained by the measure. The scores used for analysis in the second section were corrected for guessing by applying the formula presented in Kline (2000) and discussed in the previous chapter (section 3.4.4.1).

i. Reliability

Before proceeding with the regression analyses, the tasks' reliability will be examined. Although reliabilities were considered chapter, the number of items included in that chapter was different from that included here. The analysis in the preceding chapter is based on a reduced set of items. In this chapter, the control items are excluded from the scores (since they do not have a function in the analysis) and the full set of experimental items is included.

The present analyses investigates the reliability of the tasks by analysing the raw scores of the full range of time concept tasks administered to the hearing impaired children only.

The reliability co-efficient for the Place-holder task was KR20 =.85. The levels of reliability based on the full range of Change task items was KR20 =.81; These are both acceptable levels of reliability (Hammond, 1995). These measures could be used for further analyses.

ii. Description of corrected scores

A formula for correcting for guessing was applied to the present data (Kline, 2000). This formula was applied to the full set of items and the corrected scores were used in the subsequent analyses.

The distribution of the corrected scores were tested for skewness to establish whether statistical tests that assume normal distribution could be used to analyse performance on the task (Howitt & Cramer, 1997). The distribution of the corrected Place-holder task scores is presented in figure 4.5 below. Analysis showed that the data were not significantly skewed (z= -0.15; *p*<.05).

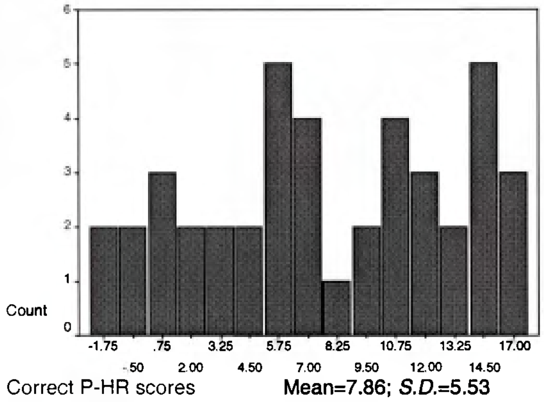


Figure 4.5 Distribution of the corrected Place-Holder task scores

The distribution of the scores for the corrected Change task scores was tested for skewness to establish whether statistical tests that assume normal distribution could be used to analyse performance on this task (Howitt & Cramer, 1997). Analysis revealed that the data were not significantly skewed (z= 1.41; *p*<.05).

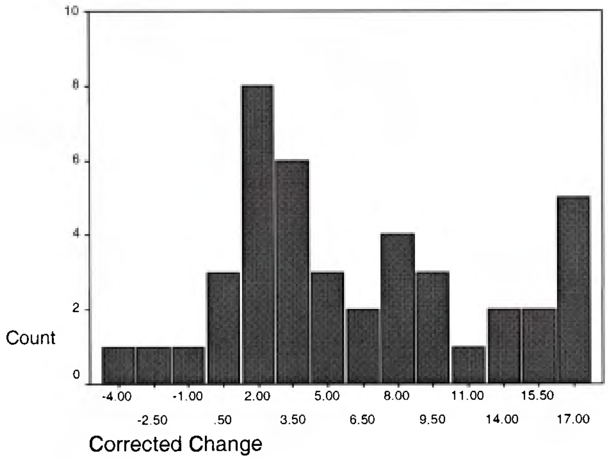


Figure 4.6 Distribution of scores on the corrected Change score

The analysis of the skewness of the corrected Change scores revealed that the measure, like the Place-holder task, can be used with statistical tests that do not assume that the data are normally distributed.

iii. Summary

Investigation of the construct validity of the experimental task confirms the results of the previous chapter in section 3.4.4.1, that the construct validity of the task is robust. However, continuous assessment of the task's validity should continue in future studies when the task is administered because the validation of a test is a cumulative and ongoing process (Hammond, 1995).

Once correction of the raw scores for the possibility of guessing was carried out, an analysis of the skewness of the corrected scores was confirmed as not being significantly skewed. It was therefore appropriate to use statistical tests that assume normality of distribution with the data. The corrected scores are analysed in subsequent analyses.

iv. Analyses of time concept tasks as explanatory variables

The correlation between NFER (1) and the time concepts tasks were: with the corrected P-HR task r=.60 (p<.001); and with the corrected Change Task r=.55

(p<.001). These correlations were significant and in the expected direction. To examine the hypothesis that scores on the time concept tasks explain a significant amount of the variance after controlling for age and intelligence, a series fixed order multiple regression analyses with each time concept task score as the third step was carried out. The results of the regression analysis are summarised in tables 4.17 and 4.18. The Change and the P-HR tasks both explained a significant amount of variance in the equation after controlling for age and IQ.

Table 4.17 Summary of fixed order multiple regression with NFER (1) standardised score as the outcome variable with age, non-verbal IQ and corrected P-HR as the predictor variables

Step	**Variable**	**R^2 change**	**B**	**SE B**	**β**
1	Age at time 1	0.17 **	0.001	0.001	0.21
2	WISC	0.15 **	0.001	0.001	0.18
3 (n = 41)	Place-holders	0.11 *	0.004	0.002	0.42

Significant F change: * p< .05, ** p< .01, *** p< .001, **** p< .0001, $^{n.s.}$ not significant

Table 4.18 Summary of fixed order multiple regression with NFER (1) standardised score as the outcome variable with age, non-verbal IQ and corrected Change as the predictor variables

Step	**Variable**	**R^2 change**	**B**	**SE B**	**β**
1	Age at time 1	0.17 **	0.001	0.001	0.19
2	WISC	0.15 **	0.001	<0.001	0.32
3 (n = 41)	Change	0.15 **	0.003	0.001	0.41

Significant F change: * p< .05, ** p< .01, *** p< .001, **** p< .0001, $^{n.s.}$ not significant

A specific relation between making inferences involving time and performance in NFER(1) was found. These tasks were significant predictors of maths score after controlling for age and non-verbal IQ. In addition the Change Task was correlated with NFER (1) score and was a significant predictor of mathematics score.

The tasks developed to assess the children's understanding of times concepts were significant predictors of mathematics ability in the concurrent analyses.

4.5.2 Summary of concurrent analyses

The present section summarises the concurrent analyses and considers which of the predictor variables contribute a significant amount of variance in the fixed order regression equations after controlling for age and non-verbal IQ score. Figure 4.5 summarises the results already presented and shows the variables that predict a significant amount of variance when NFER (1) score was the outcome measure after controlling for age and IQ. Age and non-verbal IQ together explained 32% of the variance in the equations. Figure 4.5 shows the amount of variance explained by each variable entered into the equation, the total amount of variance can be calculated by adding the variance explained by each step. It can be seen that the equation with the Shop Task explained the most variance.

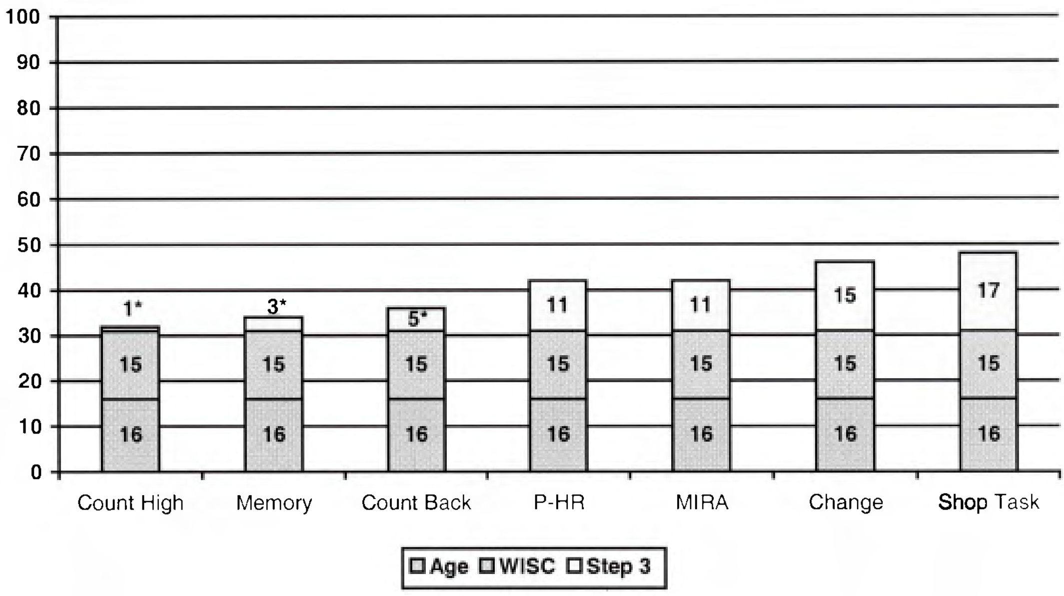


Figure 4.7 Amount of variance explained by fixed order multiple regression equations with the different tasks in the third step (Note: Number represents percentage of variance explained by each step, * = Not Significant)

Further analysis was carried out to investigate whether the significant predictors, namely the Shop Task, Change and Place-holder tasks continue to predict a significant amount of variance after controlling for language ability also. It may be that success in these three tasks reflects incidental or informal learning mediated by linguistic ability. Age and non-verbal IQ were placed in the first and second steps, language was then controlled for in the equation by placing reading comprehension score in the third step. Lastly the predictor variable was placed in the fourth step. For the variables to be significant predictors they must explain a significant amount of variance in the fourth step. Figure 4.8 summarises the analyses showing the percentage of variance explained by the three equations. The complete summary tables for the regression equations are included in the Appendix. The corrected P-HR task was no longer significant when placed as the fourth step of the equation: the score on the Shop Task was still significant after controlling for age, IQ and language - this equation explained 50% of the variance. The corrected Change task also added a significant amount of variance after controlling for age, IQ and reading comprehension and the equation explained 49% of the variance.

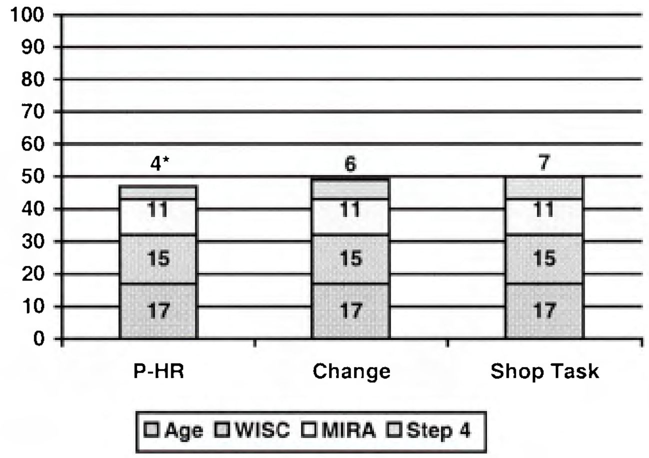


Figure 4.8 Percentage of variance explained in fixed order regression equations with NFER (1) as the outcome measure, controlling for age, IQ and reading comprehension (Note: Number represents percentage of variance explained by each step, * = Not Significant)

It can be seen that the Shop Task still explains a significant amount of variance even after controlling for age, non-verbal IQ and linguistic ability.

The analyses in the present section explored the relations between variables administered concurrently. The direction of causality can not be assumed in this case. For a causal test of these relations, longitudinal analyses were carried out. In this way the relations between the variables administered at time 1 and mathematics assessments administered later on in the academic year can be explored. If the relations are significant and the variance explained by these variables is significant after controlling for age and non-verbal IQ, then one will have evidence to support the hypothesis of a causal connection between the predictors and deaf children's mathematics achievement.

4.6 Longitudinal analysis - Do the cognitive and linguistic variables *predict* mathematics performance longitudinally?

The following section examines the relation between various predictor variables administered in the first assessment period, during the Autumn term 1997, and mathematics scores obtained from assessments administered 4 and 8 months after the first assessment during the Spring and Summer terms in 1998. The purpose of the present analyses was to examine the longitudinal relations between the predictor variables and mathematics scores. Whereas it is not possible to make inferences about causality in analyses of concurrently obtained measures, longitudinal prediction can contribute to clarifying the direction of the causal connection.

4.6.1 Examination of the predictor variables

As in the previous analyses, each predictor variable is examined in turn. In each section the hypothesis is tested by examining the relation between the predictor variable and mathematics scores obtained at time 2 (Number Age) and time 3 (NFER(3)). For the hypothesis to be supported, the predictor must be significantly correlated with the mathematics score and be a significant predictor of mathematics score above and beyond age and non-verbal IQ.

4.6.1.1 Memory capacity as the explanatory variable

It was hypothesised by Hitch *et al.* (1983) and Epstein *et al.* (1990) that the memory capacity scores are positively correlated with standardised mathematics scores and will be a significant predictor of mathematical ability. This is because, according to this model, smaller memory capacities will directly influence ability to process number.

The correlation between the memory capacity score and Number age was $r=.60$ ($p<.001$) and the correlation between memory capacity score and the NFER (3) score was $r=.40$ ($p=.01$). Two fixed order regression analyses were carried out to test the hypothesis that memory capacity predicts performance in standardised mathematics assessments after controlling for age and non-verbal IQ. Tables 4.19 and 4.20 summarise the results of the regression analyses.

Table 4.19 Summary of fixed order multiple regression with Number age as the outcome variable with age, non-verbal IQ and memory capacity as the predictor variables

Step	**Variable**	**R^2 change**	**B**	**SE B**	**β**
1	age at time 2	0.29 ***	0.56	0.19	0.32
2	WISC	0.29 ****	0.39	0.10	0.44
3 (n = 41)	Memory capacity	0.07 *	2.48	0.95	0.30

Significant F change: * $p< .05$, ** $p< .01$, *** $p< .001$, **** $p< .0001$, $^{n.s.}$ not significant

Table 4.20 Summary of fixed order multiple regression with NFER (3) as the outcome variable with age, non-verbal IQ and memory capacity as the predictor variables

Step	**Variable**	**R^2 change**	**B**	**SE B**	**β**
1	Age at time 3	0.24 **	0.003	0.001	0.34
2	WISC	0.16 **	0.002	0.002	0.38
3 (n = 40)	Memory capacity	<0.01 $^{n.s.}$	0.004	0.006	0.10

Significant F change: * $p< .05$, ** $p< .01$, *** $p< .001$, **** $p< .0001$, $^{n.s.}$ not significant

Although memory capacity and mathematics scores were significantly associated, the measure of memory capacity was not a consistent predictor of mathematics score longitudinally. It was a significant predictor on one occasion but not on the other.

4.6.1.2 Response times as the explanatory variables

It was hypothesised by Epstein *et al.* (1990) that number processing speed would be related to and predictive of mathematical ability. According to the model, the relation between the response times to the correct responses in the memory scan task and the two mathematics assessments should be negative. Those children responding more quickly in the memory scan task would be processing number more efficiently and therefore obtaining higher scores in the mathematics assessments. The correlations of the response scores with both the maths assessments are presented in tables 4.21 and 4.22.

Table 4.21 Correlations between response times in memory scan task and Number Age

Task	**SSS1**	**SSS2**	**SSS3**	**SSS4**	**SSS5**	**SSS6**
Negative probes						
r	-.23	-.35	-.32	-.24	-.53	-.19
p	.16	.03	.048	.14	.001	.24
n	40	39	39	39	37	38
Positive probes						
r	-.32	-.32	-.41	-.38	-.37	-.52
p	.04	.04	.01	.02	.02	.001
n	40	40	40	40	38	35

Table 4.22 Correlations between response times in memory scan task and NFER (3) score

Task	**SSS1**	**SSS2**	**SSS3**	**SSS4**	**SSS5**	**SSS6**
Negative probes						
r	-.31	-.39	-.39	-.59	-.54	-.29
p	.50	.02	.01	<.01	<.01	.07
n	40	39	39	39	37	38
Positive probes						
r	-.22	-.34	-.34	-.43	-.46	-.49
p	.17	.03	.03	<.01	<.01	<.01
n	40	40	40	40	38	35

Two sets of regression analyses were carried out. Age and WISC score were placed as the first and second steps in a fixed order regression equation. The response times for each task condition were placed as the third step. The outcome variables were the standardised maths scores. Table 4.23 summarises the results of the analyses with Number age as the outcome variable. Table 4.24 summarises the results of the regression analyses with NFER (3) as the outcome variable. Only one of the variables contributed a significant amount of variance in step 3 at time 2 of testing. At time 3, again, only two of the predictor variables contributed a significant amount of variance after controlling for age and WISC score. It was not the same significant predictor variables as in time 2.

Table 4.23 Summary of the fixed order regression equations with Number age as the outcome variable with age, non-verbal IQ and response time in the memory scan task as the predictor variables

Step	Variable	R^2 change	B	SE B	β
1†	Age at 2	0.29 ***	0.66	0.19	0.37
2†	WISC	0.29 ****	0.48	0.10	0.55
Negative probes					
3 (n = 41)	SSS1	0.03 $^{n.s.}$	-1.02	0.63	-0.17
3 (n = 40)	SSS2	<0.01 $^{n.s.}$	-0.05	0.54	-0.01
3 (n = 40)	SSS3	<0.01 $^{n.s.}$	0.04	0.78	0.006
3 (n = 40)	SSS4	<0.01 $^{n.s.}$	-0.75	1.25	-0.07
3 (n = 38)	SSS5	0.03 $^{n.s.}$	-1.69	1.17	-0.19
3 (n = 39)	SSS6	0.01 $^{n.s.}$	-0.79	0.81	-0.11
Positive probes					
3 (n = 41)	SSS1	<0.01 $^{n.s.}$	-0.40	1.21	-0.04
3 (n = 41)	SSS2	<0.01 $^{n.s.}$	-0.51	0.91	-0.06
3 (n = 41)	SSS3	0.06 *	-1.87	0.76	-0.25
3 (n = 41)	SSS4	0.02 $^{n.s.}$	-1.31	0.83	-0.18
3 (n = 39)	SSS5	0.02 $^{n.s.}$	-1.61	1.25	-1.25
3 (n = 36)	SSS6	0.03 $^{n.s.}$	-2.28	1.47	-0.20

Significant F change: * $p < .05$, ** $p < .01$, *** $p < .001$, **** $p < .0001$, $^{n.s.}$ not significant

Table 4.24 Summary of fixed order multiple regression analysis with NFER (3) as the outcome variable with age, non-verbal IQ and response time in the memory scan task as the predictor variables

Step	**Variable**	**R^2 change**	**B**	**SE B**	**β**
1†	Age at 3	0.24 **	0.003	0.001	0.35
2†	WISC	0.16 **	0.002	0.001	0.40
Negative probes					
3 (n = 41)	SSS1	0.06 *	-0.008	0.004	-0.25
3 (n = 40)	SSS2	0.01 $^{n.s.}$	-0.003	0.003	-0.51
3 (n = 40)	SSS3	0.02 $^{n.s.}$	-.0005	0.005	-0.17
3 (n = 40)	SSS4	0.22 ***	-0.03	0.006	-0.49
3 (n = 38)	SSS5	0.05 $^{n.s.}$	-0.01	.0007	-0.29
3 (n = 39)	SSS6	0.05 $^{n.s.}$	-0.008	0.005	-0.23
Positive probes					
3 (n = 41)	SSS1	<0.01 $^{n.s.}$	0.002	.0007	0.04
3 (n = 41)	SSS2	0.01 $^{n.s.}$	-0.004	0.006	-0.11
3 (n = 41)	SSS3	0.04 $^{n.s.}$	-0.008	0.005	-0.21
3 (n = 41)	SSS4	0.02 $^{n.s.}$	-0.007	0.006	-0.17
3 (n = 39)	SSS5	0.05 $^{n.s.}$	-0.01	.0008	-0.23
3 (n = 36)	SSS6	0.03 $^{n.s.}$	-0.01	0.01	-0.21

Significant F change: * $p< .05$, ** $p< .01$, *** $p< .001$, **** $p< .0001$, $^{n.s.}$ not significant

The hypothesis was not supported. Although the majority of the response time variables were negatively and significantly correlated with the mathematics scores, only the response time for one positive probe added a significant amount of variance when Number Age was the outcome variable. At time 3, when NFER (3) was the outcome variable, the response times for two negative probes added a significant amount of variance. In each case the stimulus set size was different. Because of this inconsistent pattern of results, the hypothesis was not supported.

The measures of memory capacity and response times did not give a consistent pattern of significant results, so the hypothesis that memory predicts mathematical attainment was not supported.

4.6.1.3 Language assessment as the explanatory variable

It was hypothesised that linguistic ability would predict mathematical ability. The present section examines the MIRA reading comprehension score alone because this was the only language assessment administered in time 1. As mentioned previously there was a floor effect in the assessment. Two receptive language sub-tests from the CELF-R assessments were administered at time 3. The reading comprehension scores and the two CELF-R sub-tests were significantly correlated (Oral Directions r=.69, p<.001; Sentence Structure r=.59, p<.001). The high correlations indicate that the MIRA could be used as an indication of linguistic ability. Concurrent analyses of the CELF sub-tests and NFER(3) were carried out and presented in section 4.5.1.3.

The correlation between the reading comprehension raw score and the Number age score was ρ= .57 (p<.01). The correlation between the reading comprehension score and the NFER (3) score was ρ=.60 (p<.01). To test the hypothesis that language ability predicts performance in mathematics, fixed order regression analyses were carried out. The analyses are summarised in tables 4.25 and 4.26. Score on the MIRA reading comprehension task was a significant predictor of maths score both at time 2 and time 3.

Table 4.25 Summary of fixed order multiple regression with Number Age as the outcome variable with age, non-verbal IQ and MIRA as the predictor variables

Step	**Variable**	**R^2 change**	**B**	**SE B**	**β**
1	Age at time 2	0.29 ***	0.37	0.19	0.21
2	WISC	0.29 ****	0.42	0.09	0.48
3 (n = 40)	MIRA	0.11 **	1.72	0.49	0.39

Significant F change: * p< .05, ** p< .01, *** p< .001, **** p< .0001, $^{n.s.}$ not significant

Table 4.26 Summary of fixed order multiple regression with NFER (3) as the outcome variable with age, non-verbal IQ and MIRA as the predictor variables

Step	Variable	R^2 change	B	SE B	β
1	Age at time 3	0.24 **	0.001	0.001	0.17
2	WISC	0.16 **	0.001	0.001	0.28
3 (n = 40)	MIRA	0.15 **	0.01	0.003	0.47

Significant F change: * *p*< .05, ** *p*< .01, *** *p*< .001, **** *p*< .0001, $^{n.s.}$ not significant

The hypothesis was supported, linguistic ability, as measured by the reading comprehension raw score, was significantly correlated to both of the mathematics assessments and added a significant amount of variance after controlling for age and non-verbal IQ.

4.6.1.4 Shop Task as the explanatory variable

It was hypothesised that understanding of the additive composition of number would predict attainment in standardised mathematics assessments. The categories of performance in the Shop Task were used as a measure in these equations as they were at time 1. The correlations between the Shop Task score and the standardised maths scores were ρ=.74 (*p*<.001) with the Number age score and ρ=.65 (*p*<.001) with the NFER (3) score. Two fixed order regression analyses were carried out - tables 4.27 and 4.28 summarise the results of the analyses. Score on the Shop Task was a significant predictor of maths score both at time 2 and time 3 after controlling for age and WISC score.

Table 4.27 Summary of fixed order multiple regression with Number age as the outcome variable with age, non-verbal IQ and score on the Shop Task as the predictor variables

Step	Variable	R^2 change	B	SE B	β
1	Age at time 2	0.29 ***	0.38	0.19	0.22
2	WISC	0.29 ****	0.35	0.09	0.40
3 (n = 40)	Shop task	0.12 ***	6.20	1.65	0.43

Significant F change: * *p*< .05, ** *p*< .01, *** *p*< .001, **** *p*< .0001, $^{n.s.}$ not significant

Table 4.28 Summary of fixed order multiple regression with NFER (3) as the outcome variable with age, non-verbal IQ and score on the Shop Task as the predictor variables

Step	Variable	R^2 change	B	SE B	β
1	Age at time 3	0.24 **	0.001	0.001	0.17
2	WISC	0.16 **	0.001	0.001	0.18
3 (n = 40)	Shop task	0.18 ****	0.04	0.01	0.55

Significant F change: * $p < .05$, ** $p < .01$, *** $p < .001$, **** $p < .0001$, $^{n.s.}$ not significant

The hypothesis was supported. Score on the Shop Task was positively correlated with the mathematics scores and added a significant amount of variance after controlling for age and non-verbal IQ.

4.6.1.5 Mental operations involving time concepts as the explanatory variable

It was hypothesised that there would be a positive and significant relation between ability to manipulate information relating to time concepts and performance in the maths assessments. This was assessed with a number of correlation and regression analyses with the corrected Place-holder and Change tasks. For the hypothesis to be supported a number of results are required. Firstly, score on the corrected Place-holder task should be correlated with scores on the mathematical assessments and secondly, the corrected Place-holder task should predict mathematics attainment after controlling for age and non-verbal IQ. Thirdly, the corrected Change should be correlated with and explain a significant amount of variance after controlling for age and non-verbal IQ. Table 4.29 shows the correlation of each of the time concepts tasks with both of the standardised assessments. Both the tasks were significantly correlated with mathematics attainment.

Table 4.29 Correlation between maths assessments at time 2 and time 3 and score on time concept tasks

Task	**Number Age**	**NFER (3)**
Corrected Place-holder	.76 (*p*<.01)	.65 (*p*<.01)
Corrected Change	.55 (*p*<.01)	.69 (*p*<.01)

A series of fixed order regression analyses was carried out with age and WISC score in the first and second steps and score in the time concept tasks in the third step. Tables 4.30 to 4.33 show the summaries of each of the regression analyses. The tasks all added a significant amount of variance when placed in the third step of the equation when Number age and NFER (3) were the outcome measures.

Table 4.30 Summary of fixed order multiple regression with Number age as the outcome variable with age, non-verbal IQ and score on the Corrected Place-holder Task as the predictor variables

Step	**Variable**	**R^2 change**	**B**	**SE B**	β
1	Age at time 2	0.29 ***	0.51	0.16	0.29
2	WISC	0.29 ***	0.26	0.10	0.30
3 (n = 40)	Corrected Place-holder	0.15 ****	1.11	0.25	0.49

Significant F change: * *p*< .05, ** *p*< .01, *** *p*< .001, **** *p*< .0001, $^{n.s.}$ not significant

Table 4.31 Summary of fixed order multiple regression with NFER (3) as the outcome variable with age, non-verbal IQ and score on the Corrected Place-holder Task as the predictor variables

Step	**Variable**	**R^2 change**	**B**	**SE B**	β
1	Age at time 3	0.24 **	0.002	0.001	0.27
2	WISC	0.16 **	0.001	0.001	0.16
3 (n = 40)	Corrected Place-holder	0.11 **	0.005	0.002	0.44

Significant F change: * *p*< .05, ** *p*< .01, *** *p*< .001, **** *p*< .0001, $^{n.s.}$ not significant

Table 4.32 Summary of fixed order multiple regression with Number age as the outcome variable with age, non-verbal IQ and score on the Corrected Change Task as the predictor variables

Step	Variable	R^2 change	B	SE B	β
1	Age at time 2	0.29 ***	0.53	0.18	0.30
2	WISC	0.29 ****	0.44	0.09	0.50
3 (n = 40)	Corrected Change	0.10 **	0.71	0.21	0.33

Significant F change: * $p< .05$, ** $p< .01$, *** $p< .001$, **** $p< .0001$, $^{n.s.}$ not significant

Table 4.33 Summary of fixed order multiple regression with NFER (3) as the outcome variable with age, non-verbal IQ and score on the Corrected Change Task as the predictor variables

Step	**Variable**	R^2 change	B	SE B	β
1	Age at time 3	0.24 ***	0.002	0.001	0.22
2	WISC	0.16 ***	0.001	0.001	0.29
3 (n = 40)	Corrected Change	0.22 ****	0.01	0.001	0.51

Significant F change: * $p< .05$, ** $p< .01$, *** $p< .001$, **** $p< .0001$, $^{n.s.}$ not significant

The hypothesis was supported the corrected Place-holder and Change tasks both predicted mathematics score after controlling for age and non-verbal IQ.

4.6.2 Summary of longitudinal analyses

The following graphs summarise the results of the analyses and show the amount of variance explained by each of the equations where the third step in the equation added a significant amount of variance. In figure 4.9, Number age was the outcome measure and in figure 4.10, NFER (3) was the outcome measure. Age and WISC score together in steps one and two explained 58% of the variance when Number age was the outcome measure, and 40% when NFER (3) was the outcome measure.

It can be seen by comparing the two graphs that the Shop Task, reading comprehension, corrected P-HR, and corrected Change Tasks were all consistent predictors of mathematics score across both time 2 and time 3. Of these predictor variables, the reading comprehension, Shop Task, corrected Place-holder and Change tasks were also significant predictors in the simultaneous analyses.

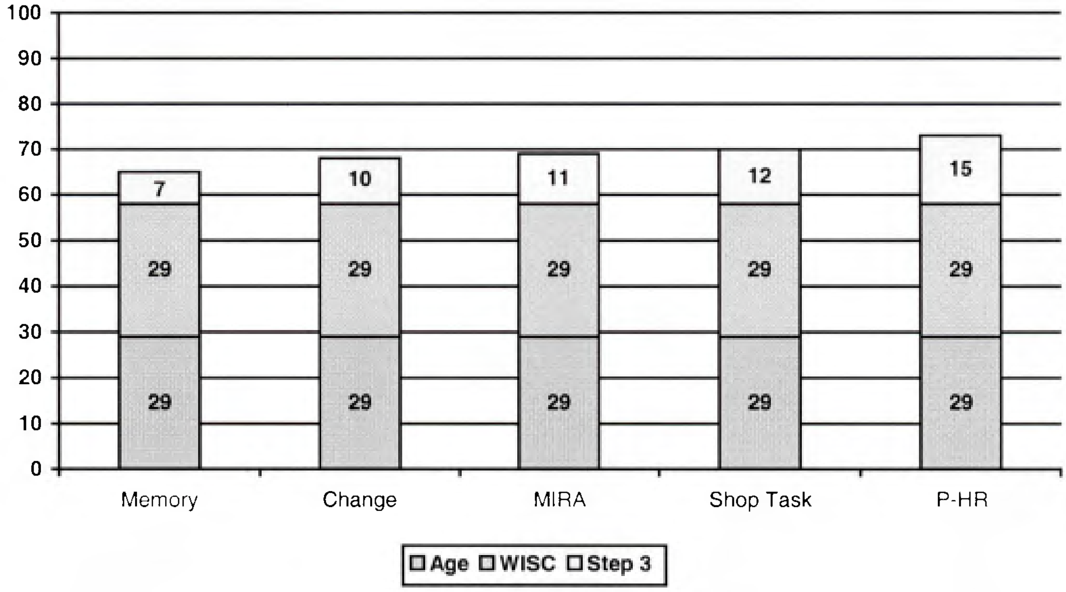


Figure 4.9 Summaries of fixed order regression analyses with Number Age as the outcome measure

(Note: Numbers represent the percentage of variance explained by each step; * Not Significant)

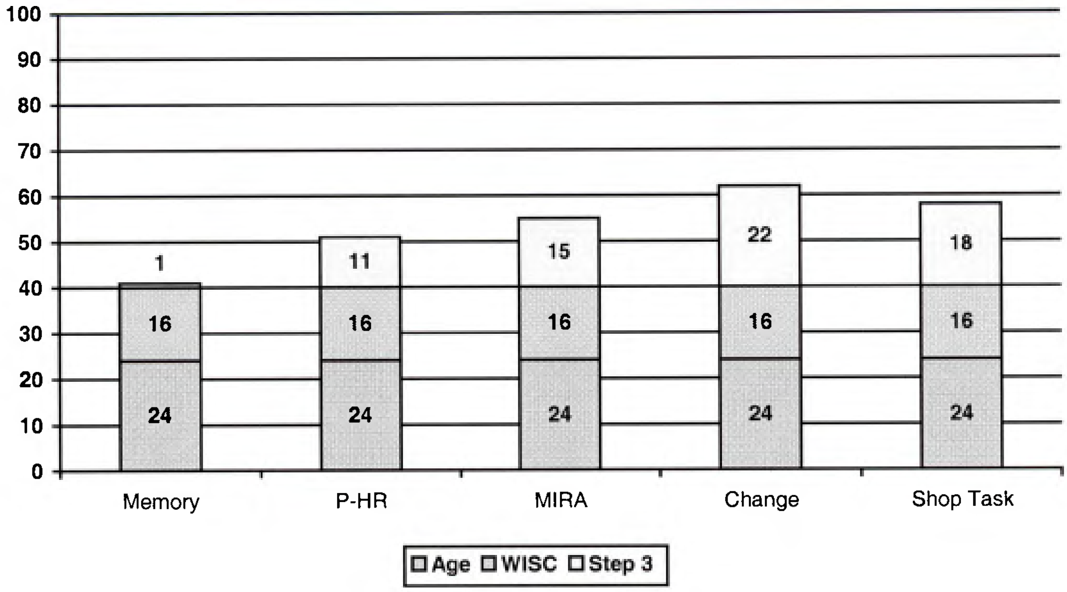


Figure 4.10 Percentage of variance explained with NFER (3) as the outcome measure. Numbers represent the percentage of variance explained by each step (Note: Numbers represent the percentage of variance explained by each step; * Not Significant)

Further analyses were carried out to investigate whether the significant predictors continued to predict a significant amount of variance after controlling for language ability also. It may be that success in these three tasks reflects incidental or informal learning mediated by linguistic ability. As in the simultaneous analysis, age and non-verbal IQ were placed in the first and second steps, language was then controlled for in the equation by placing reading comprehension score in the third step. Lastly the predictor variable was placed in the fourth step. For the variables to be significant predictors they must explain a significant amount of variance in the fourth step. Figure 4.11 shows the percentage of variance explained by each of the equations.

Examination of correlations with the time concepts tasks and the maths assessments controlling for the MIRA reading comprehension score (see Appendix C) shows that corrected Place-holder Task was significant with both number age and NFER (3). The corrected Change Task was significantly correlated with NFER (3) only.

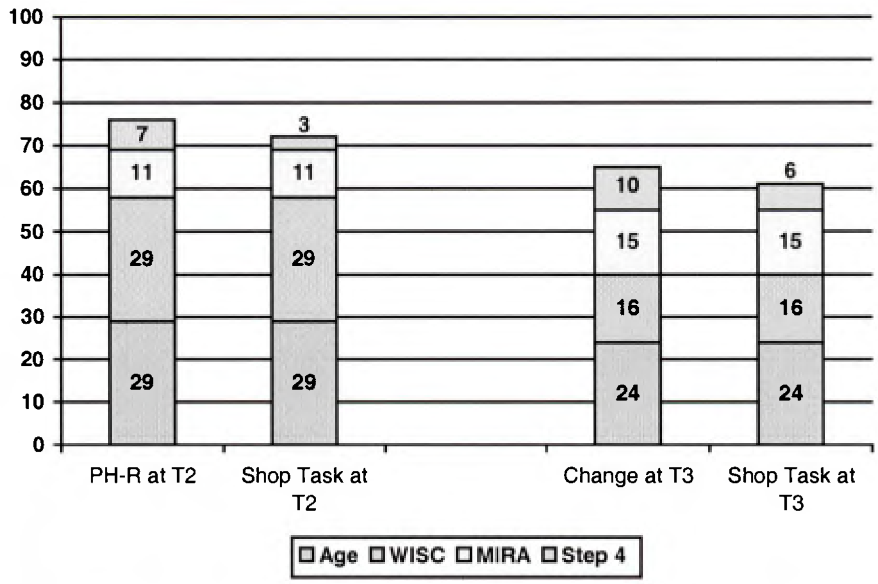


Figure 4.11 Graph to show percentage of variance explained when controlling for language at Time 2 (T2) and Time 3 (T3). Only equations with significant predictors at step 4 are shown

With Number age as the outcome variable and controlling for the MIRA reading comprehension score as well as the age and WISC score in the first and second steps, two tasks added a significant amount of variance in the fourth step. These were the Shop Task and the Place-holder task. The total amount of variance explained by the equation was 76% with the Place-holder Task and 72% with the Shop Task. When NFER (3) was the outcome variable, the Shop Task continued to add a significant amount of variance and the corrected Change task added a significant amount of variance. The total amount of variance explained by these equations was 61% with the Shop Task and 65% with the corrected Change Task.

4.7 Conclusions

The aim of the present study was to examine the relations between various explanatory variables and mathematics scores. Three sets of analyses were carried out. The first set examined the relations between mathematics and demographic variables that were general and specifically associated with hearing impairment. Only age was significantly and consistently associated with mathematics scores. It was concluded that further analyses should control for age. The second set of analyses examined the relations between the predictor variables and mathematics assessments that had been administered concurrently. These analyses controlled for age and performance IQ in order to explore the specific relation between the predictor task and the mathematics assessment. The language assessments, two time concept tasks and the Shop Task were all significant predictors of mathematics attainment after controlling for age and IQ. After controlling for the measure of linguistic ability, one time concept task and the Shop task continued to be a significant predictor of mathematics attainment.

The third set of analyses examined the longitudinal relations between the predictor tasks administered at time one and the mathematics assessments administered four and seven months later. Language, the two time concept tasks and the Shop tasks were consistent predictors after controlling for age and IQ longitudinally. Memory capacity was not a consistent predictor longitudinally. After controlling for linguistic ability in addition to age and IQ the Shop task remained a consistently significant predictor. One Time concepts task was a significant predictor for the assessment administered four months later after controlling for age IQ and language. The other Time concept task was a significant predictor for the mathematics assessment administered seven months later after controlling for age, IQ and language.

The study found that the most significant predictors of mathematics in hearing impaired children were language ability, time concepts and the Shop Task. In addition, however, the results suggest that the concepts measured in the Shop task and the Time concept tasks are not just skills that are based solely on linguistic ability, they continue to explain a significant amount of variance after the MIRA scores were controlled for.

5. Discussion and Conclusions

The present study examined the causes of lower mathematical ability in hearing impaired children. Two criteria were stipulated for a particular skill to be identified as a possible cause of delay in mathematics. First, the hearing impaired children have to demonstrate a delay in measures of the skill in comparison with hearing children and second, these measures have to be significant predictors of mathematics achievement when age and intelligence are controlled for. Two studies were designed and a range of tasks and measurements was administered to hearing and hearing impaired children. The first of the two studies was designed to investigate whether the hearing impaired children demonstrated a delay in task achievement. The second study was designed to examine the relations between performance in these tasks and mathematics scores and to investigate whether they predicted mathematics achievement longitudinally. Only those measures that were significant in both of the studies could be considered as causes of delay in the mathematics in hearing impaired children. The following section summarises the results for each of the measures in turn and examines whether they meet the criteria set out in the thesis.

5.1 Assessing the measures

5.1.1 Relation between demographic variables and mathematical ability

The relations between mathematics scores and demographic variables were explored. There was little support for the idea that factors associated with hearing impairment cause the lower mathematical attainment levels found in hearing impaired children. In other words, there was no support for the idea that there is something inherent about hearing impairment per se that causes low achievement in mathematics. This replicates results observed by Wood *et al.* (1986) and leads to the conclusion that alternative causes of lower attainment need to be investigated.

5.1.2 Is short term memory a cause of low mathematical ability in hearing impaired children?

Short term memory was measured by a memory scan task. The present task was designed to assess short term memory and number processing skills. In the measure of memory capacity the hearing impaired had smaller capacities than their hearing counterparts. On average the hearing children were able to deal with information that held a longer list of numbers than the hearing impaired children. The speed with which the numbers were processed was also examined. The hearing impaired children were slower than the hearing children when performing the task. These findings replicated research carried out previously by Hitch *et al.* (1983), Epstein *et al.* (1990) and Chincotta and Chincotta (1996).

In addition to this, the present study examined the relation between these measures of memory capacity, number processing speed and mathematics scores. Number processing speed was not a significant predictor of mathematical ability. Memory capacity was an inconsistent predictor. Only one of the two causal criteria was satisfied. Even though the hearing impaired children showed less ability on the memory scan task, this is not likely to be the cause of lower attainment of mathematical ability in hearing impaired children.

5.1.3 Is language ability a cause of low mathematical ability in hearing impaired children?

The hearing impaired children were administered standardised assessments of linguistic ability. Unsurprisingly, the children's scores were behind the norms on the standardised measures of reading comprehension and receptive language ability. Many of the children were unable to obtain a standardised score on the measure of reading comprehension. When the measures of linguistic ability were examined to establish whether they were significant predictors of mathematical ability, it was found that both the reading comprehension and one of the receptive language scores were significant. This satisfied both the criteria, the impoverished language ability of hearing impaired children can be considered as a cause of the lower mathematical ability of this group. This result is not very surprising given that a large proportion of mathematics curriculum is about learning conventions, which are passed on to the child through language. This is an area where hearing impaired children are particularly at risk.

5.1.4 Is early numerical ability a cause of low mathematical ability in hearing impaired children?

Early numerical ability was measured with a number of tasks. Counting to the highest number, counting backwards and knowledge of the additive composition of number, as measured by the Shop Task. The hearing and hearing impaired children were compared directly on the Shop Task and the hearing impaired children were behind their hearing counterparts. When this task was examined in regression analyses, score on the Shop Task was a significant predictor of mathematical ability assessed on three separate occasions. The counting tasks were not consistent predictors of score on the mathematics assessments. Counting to the highest number was never a significant predictor of mathematics score in hearing impaired children. Counting backwards was an inconsistent predictor. This indicates that the ability to count and recite the number sequence is not enough to predict performance in formal mathematics assessments. More over it suggests that the tasks designed to assess counting skills and additive composition were measuring different concepts. Understanding of the number system is a much more important predictor with hearing impaired children aged between 7- and 8-years of age.

5.1.5 Is understanding of mental operations involving time concepts a cause of lower mathematical ability in hearing impaired children?

Two tasks were designed to assess the ability to reason about time concepts. The first was based on the ability to identify a picture sequence on the basis of given sequential information. The task assessed the ability to use ‘place-holders’ when the sequential information given to the children was incomplete. The second task assessed the ability to infer the initial status of a situation involving change. In the comparative study the hearing impaired children obtained fewer correct answers than the hearing children did for both tasks. These tasks were also significant predictors of mathematics scores in the longitudinal study. The hearing impaired children who performed better in these tasks at the beginning of the school year also performed better in standardised mathematical assessments throughout the school year even after controlling for age and IQ.

5.1.6 Controlling for language ability

As mentioned previously, linguistic ability was a significant predictor of mathematical ability. It is also possible that the other tasks found to significantly predict mathematical ability are simply indicators of how logico-mathematical reasoning is mediated by linguistic ability. This would mean that the same skills are being measured twice. In order to investigate this, relations between the predictor tasks and mathematics were explored again while controlling for age, non-verbal intelligence and language in the longitudinal study. In this way it was possible to examine whether any of the other predictors continued to predict mathematics performance over and above linguistic ability. In this analysis score on the Shop Task continued to be a consistent, significant predictor of mathematics performance. The two different tasks assessing time were, each on different occasions, also longitudinal predictors of mathematical achievement after linguistic ability was controlled for. These results strongly support the hypothesis that additive composition and the ability to carry out mental operations on time organisation of events, are specific predictors of mathematics achievement and are likely to be causally involved in the hearing impaired children's low mathematical attainment.

5.2 Implications of the study for current theory

In chapter one, different theories about the cognition of the hearing impaired were considered. These theories questioned whether the cognition of deaf people is qualitatively and/or quantitatively different to the cognition of hearing people. The last two approaches discussed were those generated by Piagetian and Vygotskian theory. Piagetian theory predicts that children will initially learn mathematical concepts through representing problems with action and the application of 'action schemas'. Vygotskian theory suggests that mathematics is a 'cultural practice'.

Children acquire knowledge of the conventional signs for mathematical operations by communicating with more experienced members of their society, such as their teachers (Nunes, 1996). The process of communication is more difficult for hearing impaired children than it is for their hearing classmates. It was suggested that performance in formal assessments of mathematics attainment would be predicted by those tasks that require knowledge of the conventions of the number system and that require effective communication for their transmission. In the present thesis, these were the understanding of the additive composition of number and the ability to talk and reason about concepts about time and change in situations. Vygotsky did not distinguish between methods of communication, stating that achieving intersubjectivity and ensuring that the information being transmitted is being understood was the most important issue. If these ideas are correct then understanding of mathematical concepts is possible, as long as communication with hearing impaired children is supported in the method most appropriate for that hearing impaired child. The present study provides some support for the Vygotskian perspective. Along with the general linguistic ability, the concepts of additive composition and communication about change and the use of 'place-holders' in sequential information were the most consistent predictors of mathematical ability. Indeed, these remained as significant predictors even after controlling for linguistic ability. Piagetian theory also suggests that the speed of cognitive development is delayed for hearing impaired children. This was supported in the literature, hearing impaired children show a superior problem solving ability in mathematical problems when allowed to implement action schema. Nunes and Moreno (1996), for example, tested the same children on the same problems in two conditions, one where they were encouraged to implement their action schema and another more formal situation. The children performed significantly better in the first condition. The idea of a delay in numerical development also suggests that predictors of mathematical ability in hearing children should also be so for hearing impaired children. This was also supported in the present study. The Shop Task was found to be a significant predictor of mathematics attainment in hearing children by Nunes *et al.* (1991), it was also found to be so by Nunes and Moreno (1998b) and again in the present study.

5.3 Limitations of the study

5.3.1 The sample

Around 40 hearing impaired children, all from urban environments and attending state day schools located in areas considered to be in a middle to lower social strata took part in the study. It would be unwise to state that this sample is representative of all British hearing impaired children. One point of difference about the children in the present study is that they obtained a relatively low mean performance IQ score. This was not expected because previous studies found no significant differences between hearing and hearing impaired samples in performance IQ assessments (e.g. Braden, 1984). Braden (1994) did, however, find that the IQ scores of hearing impaired children born to deaf parents were higher than the IQ scores of hearing impaired children born to hearing parents. 37 of the 42 children in this sample were born to hearing parents and this may explain the lower IQ scores in the present sample, suggesting that, in this respect the children taking part in the study were not different in intelligence to other groups of hearing impaired children.

The lower performance IQ scores of the present group more probably reflect the sampling procedures employed in the study. All the hearing impaired children taking part in the study attended schools that provided special educational support, either in a special school, in a special unit based within a mainstream school. No hearing impaired children attending mainstream schools on a fully integrated basis took part in the study. It is likely that the children taking part in the study only reflects only one section of the population of hearing impaired 7- to 8-year old children. Thus by excluding hearing impaired children who are fully integrated in mainstream education it may be that those children with higher performance IQ scores were also excluded from the sample.

Indications are that the sample taking part in the study consists of a special group of children. One cannot assume that predictors of mathematics hearing impaired children who are fully integrated will be the same as those for the children taking part in the present study, nor that they will necessarily obtain lower scores in the tasks and attainments administered in the study. However, given that the same predictors of mathematics attainment have been found in previous studies with hearing children and the hearing impaired children taking part in present study, it is likely that the same tasks could predict mathematics performance in a sample of fully integrated hearing impaired children.

The communication preferences of the children taking part in the study varied from oral to reliant on sign. There were two types of signed languages that were used by the children, BSL and Signed English (or SSE). The difference in preference in signed languages may cause differences in ability to perform the tasks because the tasks were presented in Signed English. One point of difference between BSL and other signed languages (such as American Sign Language) versus spoken languages are grammatical features. The grammar in BSL is based on spatial organisation whereas spoken languages such as English present information sequentially. Signed English follows the sequential order of English and signs accompany the words as they are spoken. It could be argued that the children who prefer to communicate in BSL are potentially at a disadvantage when asked to attend to information presented in Signed English. The information is being presented in their second language and is being presented sequentially. It is difficult, in practical terms, to assess differences in task ability between the signing children who prefer to communicate in BSL or Signed English. Although it could be possible to identify the children by their communication preferences, in actuality, the two categories are not mutually exclusive. All the children taking part in this study communicated in Signed English with their teachers in the classroom. Those children who preferred BSL were also observed to communicate in Signed English or a combination of Signed English and BSL. Thus, it could be said that the children are educated in Signed English. The distinction between the two groups is difficult to make, and consequently it is not really possible to ascertain directly whether children who prefer to communicate with BSL are at a disadvantage when tasks are presented to them in Signed English. However, in the longitudinal analysis, any consequences of language preference were partialled out because language ability was controlled for in the regression equations. Any effects that language preference may have had on task performance would have been controlled for in this analysis.

5.3.2 The tasks

The differences in performance between the hearing and hearing impaired children in some tasks, particularly the time concepts tasks, could result from administration procedures favouring the hearing children over the hearing impaired children. This could be for two reasons: the nature of communication with hearing impaired children and the sequential information included in the tasks.

Communication with hearing impaired children can be problematical and requires special attention regardless of whether the child is oral or uses sign to communicate. This becomes particularly pertinent when referring to visual cues. As opposed to the hearing child who can listen to instructions while looking elsewhere, the hearing impaired child cannot simultaneously attend to the instructions and the cues. The child has to lip-read or watch the signed instructions and then look at the visual cues. After the child has attended to and understood the question, the hearing impaired child then has to process the information and answer it. This increases the time required for administering tasks to hearing impaired children in comparison to hearing children. Consequently, the hearing impaired child has to retain the information for longer than the hearing child. This could place a greater memory burden for the hearing impaired child, thus placing them at a disadvantage in comparison to their hearing counterparts. This is true not only while the children were taking part in the various tasks during the present study but it is also true for the hearing impaired children in their everyday lives, at home or in the classroom.

The tasks that may place the hearing impaired children taking part in the study at a greatest disadvantage may be those concerning sequential information. Research has found that hearing impaired children find sequential information more difficult to recall than information presented spatially. In addition, they find recalling information sequentially more difficult than hearing children (e.g. Todman & Seedhouse, 1994). The present study confirms this. This suggests that the hearing impaired children may be at a disadvantage when performing tasks that require processing of sequential information. Potentially, within the groups of hearing impaired children, who preferred to communicate in BSL may be at an even greater disadvantage because of the spatial grammar of BSL in comparison to the sequential organisation of English. It was a specific aim of the time concept tasks to investigate the difficulties hearing impaired have with sequential information. It was confirmed that the hearing impaired children found this task more difficult than the hearing children and this has implications for communicating these sequential concepts. The challenge for those in education is to develop methods of presenting sequential information spatially so that these children do not continue to be at the disadvantage when communicating about these concepts.

Concerns about this disadvantage can be reduced when the response patterns to the sequential tasks are examined. If the hearing impaired children are at a disadvantage they should then display a lower performance in both the control and the experimental items. This did not occur, comparisons on task performance between the hearing and hearing impaired children on tasks requiring the children to recall sequential information but not use place-holders, and therefore make no inferences, showed no significant differences. This suggests that the sequential presentation of information, on this particular task, did not place the hearing impaired children at a disadvantage. This may be because only a small number of items were included in the sequence. Performance differences between the two groups on the tasks requiring analysis of sequential information and the use of place-holders can then be interpreted as a difference in ability to make inferences as well as to process sequential information, rather than merely as a result of presenting the information sequentially.

5.3.3 Difficulties of communication when administering assessments to deaf children

The hearing status of the researcher is a methodological issue in research with hearing impaired participants that has been raised and investigated. It may be that hearing impaired children assessed by hearing researchers may obtain lower achievement scores because the researcher is unaware of how to communicate with hearing impaired participants. Deaf or hearing impaired adults, on the other hand, may be more aware of effective communication strategies and better able to establish good rapport with the deaf child. Consequently more effective communication with the hearing impaired participants will be achieved because of their own experiences when communicating. A number of studies have examined the researcher's role in the administration of assessments to hearing impaired children and adults.

Hindley, Hill and Bond (1993) designed a study to assess the administration of the Child Assessments Schedule (CAS) to 12 signing deaf children and adolescents in three different conditions. The CAS is a psychiatric assessment, the format of which is a highly structured diagnostic interview. In order to administer the CAS effectively, the assessor must be able to identify and clarify any ambiguities in the answers given. Three different interviewers with differing levels of signing ability administered the CAS to signing children and adolescents. A trainee child psychiatrist administered the assessment twice, on one occasion using SSE, with which the trainee psychiatrist had 'limited expertise'; and on a second occasion the assessment was given with the aid of a qualified interpreter who translated the spoken instructions to BSL and the signed answers into English. In the third condition a Deaf mental health worker administered the CAS; in this case the questions asked and the answers received were all communicated in BSL. All the interview sessions were filmed. The three interview situations yielded different numbers of symptoms and diagnoses. The Deaf assessor elicited fewer symptoms and made fewer diagnoses. The trainee psychiatrist with the interpreter elicited more abnormal findings than when the trainee assessed the children alone.

A number of factors may account for the diagnoses given to the children. First, the levels of training in theoretical aspects of mental health were different for each interviewer. Second, it was revealed that the Deaf assessor had not received sufficient training and this may have influenced the lack of diagnoses made. Thus, it is it is not a straightforward conclusion that the differences can be attributed to the interviewers' mode of communication with the youngsters. Analysis of the video recordings of the interviews suggest that the Deaf interviewer was able to detect subtle cues of sign inflexion and non-verbal communication that allowed the interviewer to follow up ambiguous answers to questions. Reviews of the video-tapes of the interviews showed that the interviewer communicating in SSE had missed these cues while concentrating on other aspects of the interview. The Deaf assessor was able to communicate more easily, and did not have to strive to engage the Deaf adolescents. It appears that the assessment with the assistance of the interpreter yielded a more complete picture of the child that when the trainee psychiatrist had assessed the child alone. However, the presence of an interpreter during interview sessions is not without its difficulties.

Gregory and Hindley (1996) discussed the difficulties that can arise when administering clinical and psychological assessments to deaf children and adolescents. A number of issues were raised and considerations noted. Examples of the general considerations raised included: the fatigue that can occur for the deaf child after long periods of concentration; and the necessity for adequate levels of lighting. More specific issues related to the assessment of the hearing impaired child raised included the confidentiality of the interview session where the assessment is taking place. Although the authors recommend that an interpreter should participate in the assessment if the deaf child's preferred communication is through sign language, they acknowledge that difficulties can occur. The interpreter, for example, may alter the relationship between the clinician and child. An interpreter who lacks experience in clinical situations may look for meaning when there is none, and thus may cause confusion for both the clinician and the child (Turner, 1996; in Gregory & Hindley, 1996). With respect to psychological assessments Gregory and Hindley (1996) state that 'poor expertise in sign language and inexperience in working with deaf children can lead to unreliable results' (p. 901), and introduces the possibility of underestimating the deaf child's potential. Gregory and Hindley (1996) make some recommendations for professionals working with deaf children: the first to establish the child's preferred language and form of communication; and secondly to be aware of any communication difficulties that may arise with the child.

Clark and Hoemann (1991) also examined the issue of administering psychological assessments and asked whether the hearing status of the researcher invalidates the test results obtained when assessing hearing impaired children. The IQ scores of hearing impaired participants assessed by hearing and deaf psychometricians were compared. Although no figures were reported, no differences in IQ scores were found as a result of the hearing status of the psychometrician. As Hindley *et al.*

(1993) and Gregory and Hindley (1996) both observe, the training that assessors receive plays an important role in the effective assessment of hearing impaired children. Effective training will include fostering an awareness of the considerations that need to be taken account when assessing deaf children generally and in the measures being administered.

The hearing status of the researcher in the present study is ambiguous. Although the researcher is hearing impaired herself, she is essentially integrated into a hearing society. The researcher signs and was schooled in a unit for hearing impaired children where other signing children attended. However, neither BSL nor SSE are the researcher's first languages and so she would not be considered a member of the Deaf community. Clark and Hoemann (1991) reported that the level of training was more important than the hearing status of the psychometrician. In the case of the present researcher, training was given. In addition to this, she has the experience of attending schools herself as a child, and working as a classroom assistant in various schools and units for hearing impaired children.

The strategies used in the present study when communicating with the hearing impaired children were based on training received, personal experience and by responding to each child's communication strategies. Such strategies included ensuring that the environment had adequate lighting and ensuring that the children were watching the researcher before communication commenced. The children were observed before any assessment and the teachers were consulted to establish the child's preferred mode of communication. In addition, the instructions for the assessments were developed and refined with the researcher's sign language teacher, a Deaf person qualified in teaching BSL. The instructions developed for the time concept task were also administered in a pilot study to identify and eliminate any problems or ambiguities. It was during the pilot study, for example, that the decision was made to include an additional request in the script. The child was asked to repeat the instructions before responding to the task. This additional request was made to ensure that the child had attended to and understood the stories told. Decisions were also made about the wording of instructions, such as the use of the word 'lady' instead of 'woman' to avoid any confusion that could arise with the word 'man' if the child relied on lip-reading. Throughout the Shop Task the child was asked the value of the counters included in the task. This was to ensure that any incorrect responses were as a result of lack of understanding of the concept being assessed and not because of failure to remember the correct values. The standardised measures were administered carefully so as not to invalidate application and administration was carried out in the preferred communication mode indicated by the child.

Although communication is always problematic, several aspects of this research suggest that reasonable levels of communication between the researcher and the children were achieved. The same researcher administered all the assessments and so differences should occur because of child related differences. An inability to communicate effectively should result in consistently low performance with no range in scores. There was a wide range of scores on all the assessments. There was also no correlation with hearing status, suggesting no bias in assessment. The sessions were filmed and the video observed by the researcher after the testing sessions to verify that the child had been engaged in attending to the instructions and the tasks. There was no visual evidence to suggest a breakdown in communication between the researcher and the children taking part in the study.

5.3.4 The power of the study

The number of children taking part in a study affects the power of the study. In the present study, in particular for the regression analyses, there was a 'large effect size', meaning that there was an 80% chance of not finding a significant effect when it was present. This means that those predictors that were not significant, the 'negative results', may in reality be significant predictors of mathematics. The first negative result obtained was the lack of association between the demographic variables associated with hearing impairment and mathematics scores. In light of the previous research findings showing no or weak associations with 500 hearing impaired children (Wood *et al.*, 1986) it is unlikely that the lack of association in the present study reflects a failure to find a true effect. New demographic variables, such as aided hearing loss were included when the information was available. These were not available for all the children so these associations were analysed with a small number of children. For example, the information about aided hearing loss was available for 29 of the 42 children; these associations should be investigated further with larger numbers of children.

The second negative result was the failure to find a consistent association between performance on the memory task and mathematical attainment. This was despite finding a significant difference between the two groups of children when performing the memory scan task.

Doubts raised about the power of the study are minimised somewhat because the internal validity of the study was increased by administering two different standardised mathematics measures. The two measures assessed different aspects of mathematics, one examining the basic numeracy aspects, such as counting skills and the four operations. The other measure assessed basic numeracy skills and, in addition to this, other mathematical skills such as problem solving and knowledge of shapes. The variables that added a significant amount of variance in the regression analyses, such as the Shop Task, were significant for both of these measures.

5.4 Recommendations for further research

Little is known about the time concepts task measure because it was developed for the present study. The time concepts tasks could be investigated further in additional studies comparing hearing and hearing impaired children. It would be interesting to examine these tasks further with a complete administration of the task to hearing children as well. In this way the differences between the hearing and hearing impaired children can be explored more fully with a factor analysis for both the hearing and hearing impaired groups. This analysis could identify whether there is a separate factor requiring inversion and inference of information. It may be that sequential information rather than the use of 'place-holders' is a separate factor. Comparison between hearing and hearing impaired participants could also indicate whether there are differences between the groups or whether the hearing impaired participants demonstrate a delay in acquiring these concepts. This could be investigated further with the large samples that are required for factor analysis.

The age range of the children in this study was limited to children aged between 7- and 8-years. A longitudinal study with different age cohorts, for example with secondary school age children, may reflect a different set of significant predictors. If however, the predictors are the same, it may suggest the reasons why many hearing impaired children do not seem to make much progress throughout their secondary school career. Moores (1996) also stated that different cohorts of hearing impaired participants in studies can vary a great deal, as far as the causes of hearing impairment are concerned, and thus there can be great variation in respect to characteristics important to academic achievement. Despite finding that the demographic factors associated with hearing impairment were not associated with mathematics scores, it may be that predictors that are significant for the present sample may differ from those of a different sample in a different study. The repetition of a longitudinal study could explore the cohort effects mentioned by Moores (1996).

One aim of the present study was to investigate the development of numeracy in hearing impaired children. The findings from the present study suggests positive ways forward in the teaching of mathematics to hearing impaired children and this should be investigated in future research. The investigative strategy implemented in the present study was longitudinal. Intervention studies are another way of investigating developmental trends (Bradley & Bryant, 1983). An intervention design strategy is appropriate to investigate those tasks that were found to be significant predictors. The predictors of particular interest are those that added a significant amount of variance in the regression equations after controlling for age, non-verbal intelligence and linguistic ability. These were two of the time concepts tasks and the Shop Task. For instance, an intervention study could be designed that examines how teaching of the concepts of additive composition affects the mathematics performance of hearing impaired children. The results in the present study suggest that teaching children additive composition of number would improve scores in the

Shop Task. This in turn would have an impact on their performance in more formal assessments of mathematics attainment.

The effectiveness of different methods for supporting communication about change and time in mathematics could also be investigated in an intervention study. Success in these intervention studies could lead to the development of teaching materials and methods for hearing impaired children to support learning in the mathematics classroom.

This study suggests that hearing impaired children do have difficulties with incidental learning and processing information related to time concepts, such as sequential information. These difficulties also predict mathematical attainment. If these difficulties can be addressed in the classroom, this suggests that the mathematics attainment of hearing impaired children can be improved in the future.

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Materials developed for the study

Child Information Sheet

General Information

Date:

Child's name:

Sex

Date of birth:

School:

Teacher's name:

Details of hearing loss:

Audiogram details:

Unaided

Right:	125	250	500	1k	2k	4k	8k
Left:	125	250	500	1k	2k	4k	8k

Aided

	125	250	500	1k	2k	4k	8k

Age at onset of hearing loss (if known):

Cause of hearing loss (if known):

Family Background:

Parents hearing or deaf:

Birth order in family:

First language spoken at home:

Does the child sign?:

Do other members of the family sign? (if so who):

School career details

Age started school

Present year at school:

Other details

Additional information not included above

Scripts for mental operations involving concepts of time

(Show pile of cards for the task) On these cards there are lots of pictures. What I would like you to do is to have a look at the pictures on the card when I show you and listen to my story for each card. On some of the cards I want you to show which picture matches, or is the same as my story (show example of an item involving sequential information). For other stories I want you to answer the questions I will ask at the end of the story (show example of a task either requiring inversion or involving change).

(Ensure that the child understands the instructions and repeat or re-word any part of the instructions if the child asks for clarification). Throughout the session, if the hearing impaired child looks away at any point the instructions are stopped. Instructions are re-commenced when eye contact is regained. If a sentence was interrupted, then the sentence is stated from the beginning again.

Tasks involving sequential information.
There were eight different types of stimuli. When the first stimuli for each type is first presented attention is brought to the drawings.
Blocks: In this story we talk about blocks. We are making a tower, which block is the first block we put down when we are building? (Child either tells, points to a block or signs). Where does the next block go? (Child signs a block on top, or points to the 'arch' block in drawing or says 'on top of the other block'). Once the child has answered the question. Good now listen to my story and tell me which drawing is the same as my story. ...

Bus queue: In this story there are some people waiting for the bus. Where is the front of the queue? (Child points, or says) If the child is correct the researcher proceeds with the story. If they are incorrect the researcher proceeds with the following question – When the bus comes who do you think will get on the bus first? (Child points) Why is that? (Child points to the bus stop or says, 'because they are next to the bus stop). Good now listen to my story and tell me which drawing is the same as my story.

Train: In this story we are talking about a train. Where is the front of the train, which one is the first carriage? (Child points to the 'engine' carriage) of the train. Good now listen to my story and tell me which drawing is the same as my story.

Cars (and traffic): Now this story is about some cars (traffic) waiting and waiting at the traffic lights. Can you see the traffic light is red? When the light changes to green, which will be the first (car) to go? (The child points to the first car in the queue.) Good now listen to my story and tell me which drawing is the same as my story.

Caterpillar: Now this story is about my caterpillar (if the child signs make sure that the child understands the sign for caterpillar because some children signed this differently in the schools the study was carried out in). No further explanation was required because the story refers to 'head and shoulders' of the caterpillar.

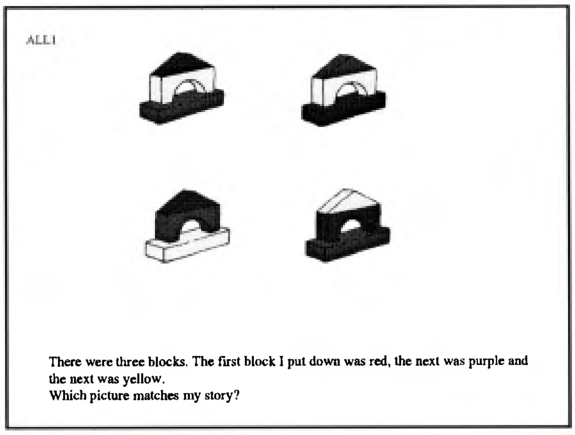
Beads: Now this story is about putting beads on a string. Have you put beads on a string? (Wait for answer) If you look at the picture what can you see at the end of the string? (Wait for child to point to or mention the knot. If it is not mentioned then it is pointed out to the child). Why do you think the knot is important? (Wait for the answer, if the child doesn't know then say it is to stop the beads falling off). So when I put beads on the string I put it on (mime threading a bead), I pull it all the way up to the knot. Where does the next bead go? (Child points to the drawing or tells me). Good, so remember the knot is important. Now listen to my story and tell me which drawing is the same as my story.

Tasks involving inversion

The story for each item was read out. Then three questions were asked. The first two followed the order presented in the question. What happened (yesterday/today)? What happened (today/yesterday)? What happened first? The method of response was pointing for all the questions. For the items with the word 'zoo', clarification of the sign was sometimes necessary because two signs for 'zoo' were used in t eh schools where the study was carried out.

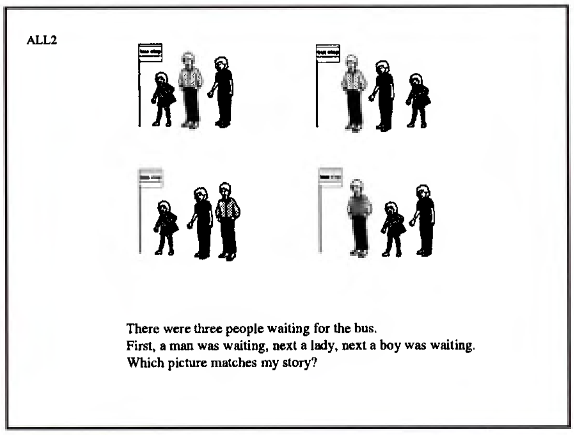
Tasks involving change

The story was told and the child was asked 'What happened in the story?' The child had to repeat the story. If the child was unable to repeat the story prompts were used in the following order: 'Who was in the story?; 'What did s/he have?'; 'Then what happened?'. After this the child was asked, 'Which drawing shows what happened first in the story, at the start of the story?' The child points at the drawing.



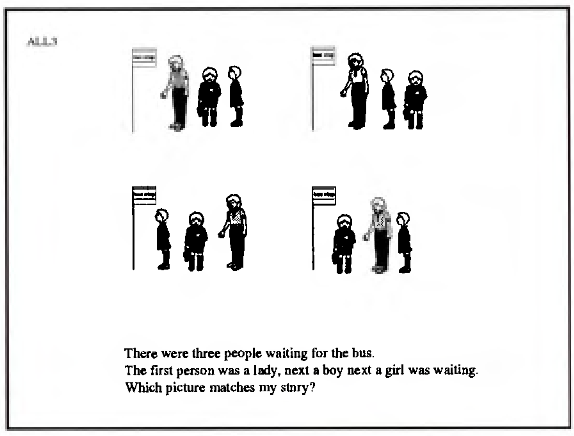
ALL1

There were three blocks. The first block I put down was red, the next was purple and the next was yellow.
Which picture matches my story?



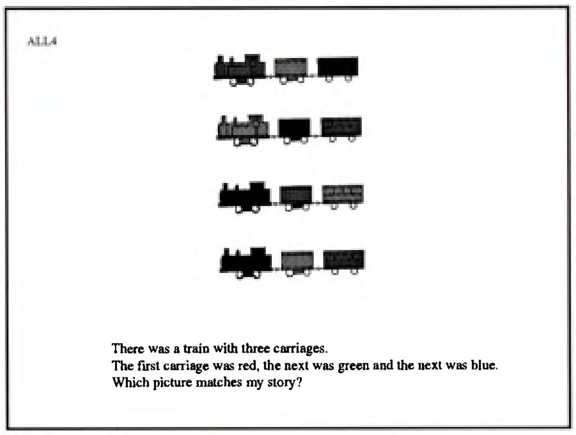
ALL2

There were three people waiting for the bus.
First, a man was waiting, next a lady, next a boy was waiting.
Which picture matches my story?



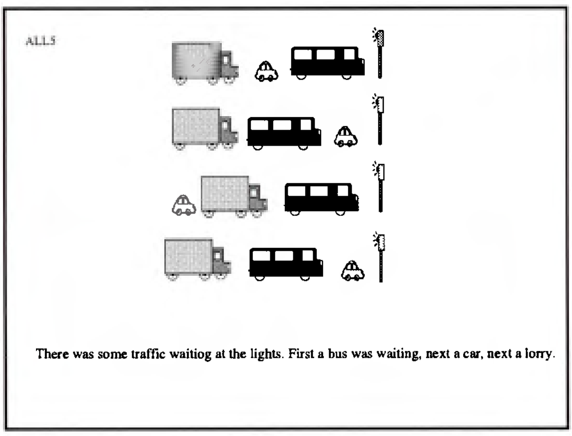
ALL3

There were three people waiting for the bus.
The first person was a lady, next a boy next a girl was waiting.
Which picture matches my story?



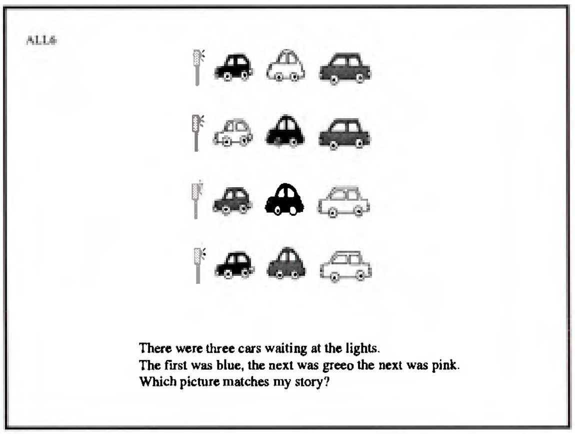
ALL4

There was a train with three carriages.
The first carriage was red, the next was green and the next was blue.
Which picture matches my story?



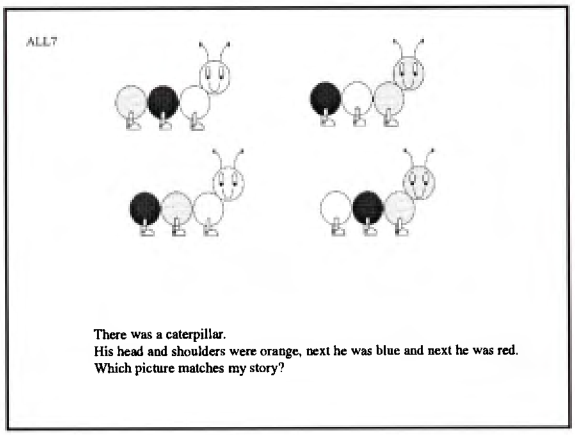
ALL5

There was some traffic waiting at the lights. First a bus was waiting, next a car, next a lorry.



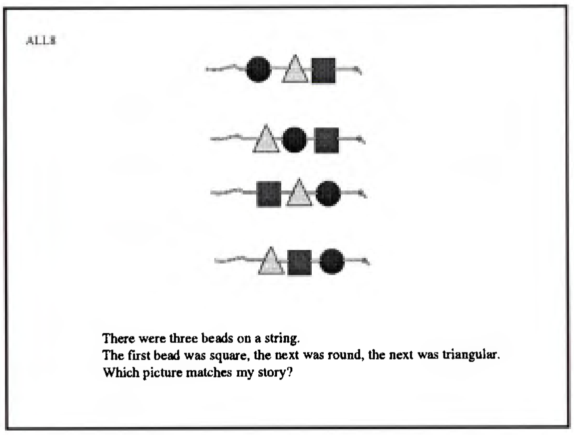
ALL6

There were three cars waiting at the lights.
The first was blue, the next was green the next was pink.
Which picture matches my story?



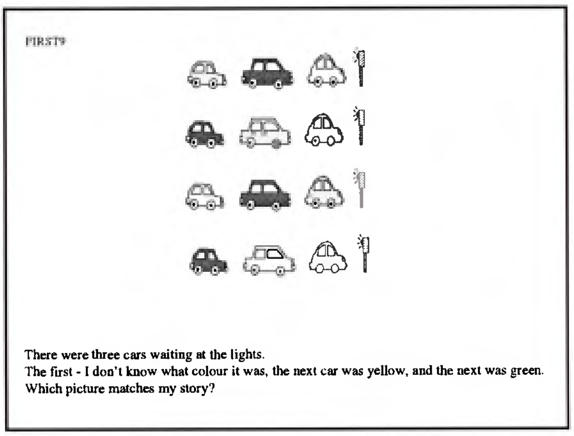
ALL7

There was a caterpillar.
His head and shoulders were orange, next he was blue and next he was red.
Which picture matches my story?



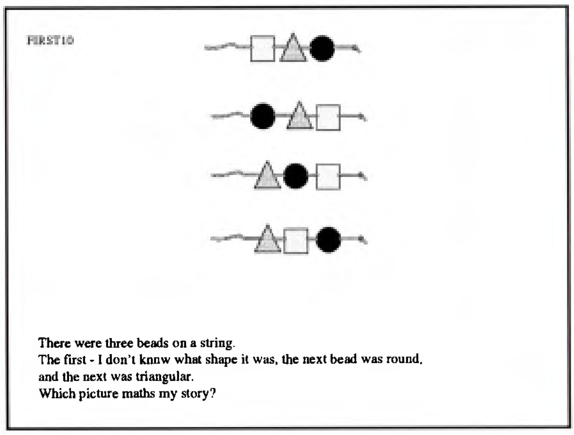
ALL8

There were three beads on a string.
The first bead was square, the next was round, the next was triangular.
Which picture matches my story?



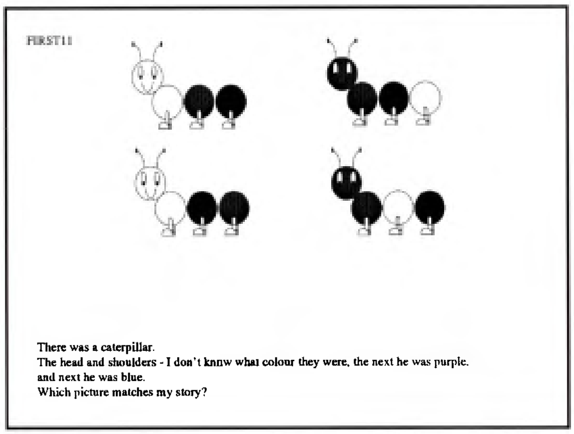
FIRST9

There were three cars waiting at the lights.
The first - I don't know what colour it was, the next car was yellow, and the next was green.
Which picture matches my story?



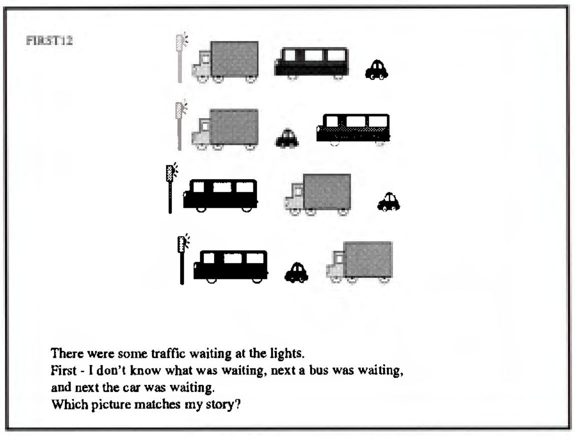
FIRST10

There were three beads on a string.
The first - I don't knnw what shape it was, the next bead was round,
and the next was triangular.
Which picture maths my story?



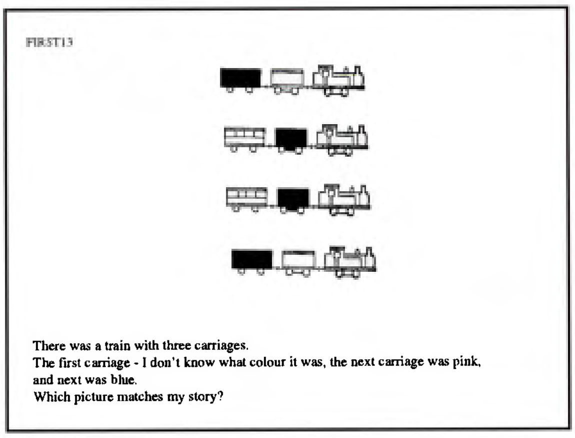
FIRST11

There was a caterpillar.
The head and shoulders - I don't knnw what colour they were, the next he was purple.
and next he was blue.
Which picture matches my story?



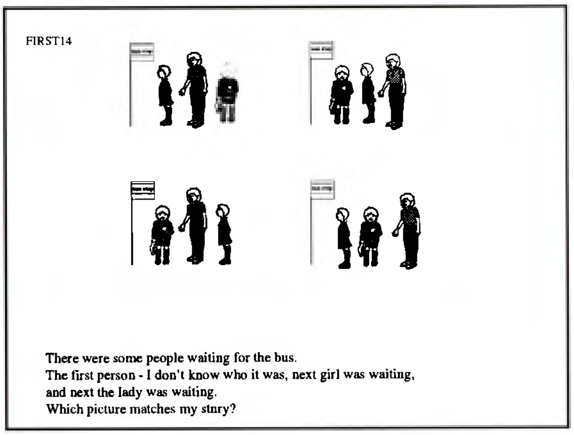
FIRST12

There were some traffic waiting at the lights.
First - I don't know what was waiting, next a bus was waiting,
and next the car was waiting.
Which picture matches my story?



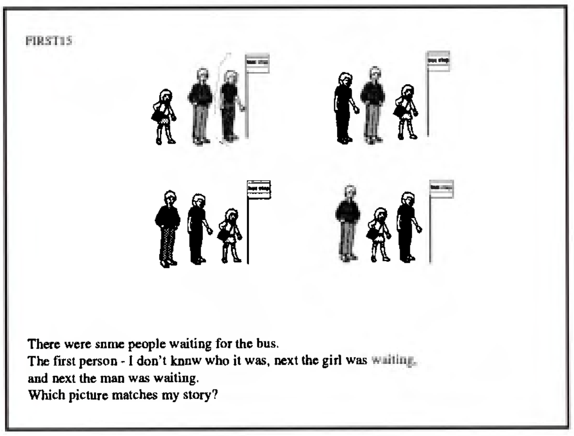
FIRST13

There was a train with three carriages.
The first carriage - I don't know what colour it was, the next carriage was pink,
and next was blue.
Which picture matches my story?



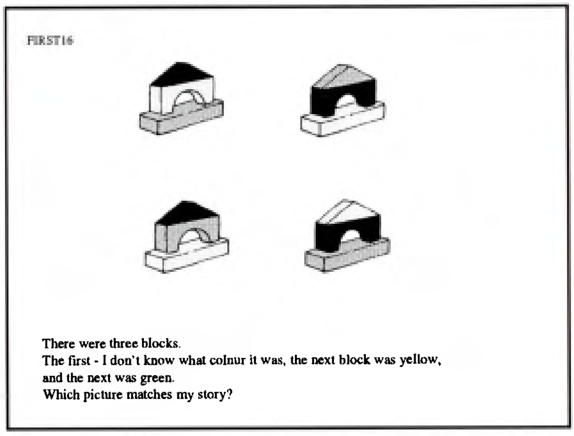
FIRST14

There were some people waiting for the bus.
The first person - I don't know who it was, next girl was waiting,
and next the lady was waiting.
Which picture matches my story?



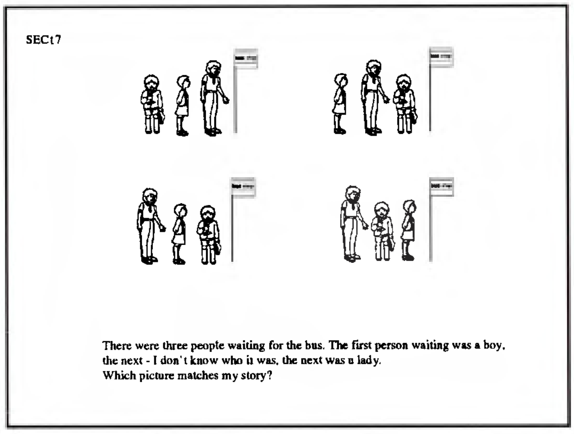
FIRST15

There were some people waiting for the bus.
The first person - I don't know who it was, next the girl was waiting,
and next the man was waiting.
Which picture matches my story?



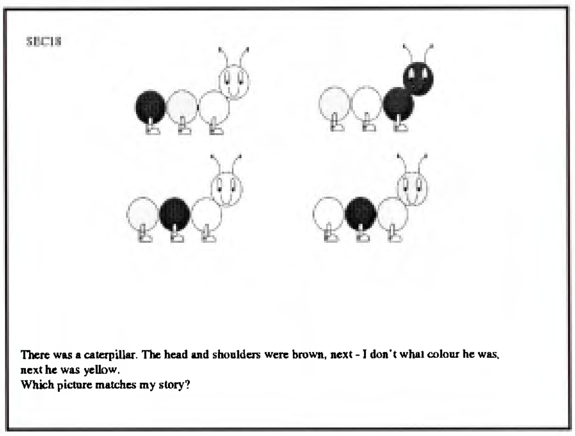
FIRST16

There were three blocks.
The first - I don't know what colour it was, the next block was yellow,
and the next was green.
Which picture matches my story?



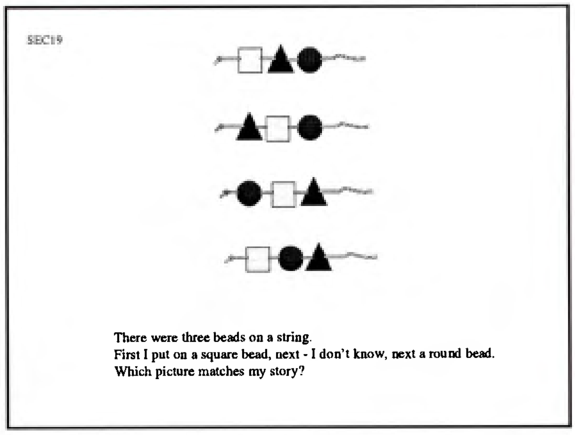
SEC17

There were three people waiting for the bus. The first person waiting was a boy,
the next - I don't know who it was, the next was a lady.
Which picture matches my story?



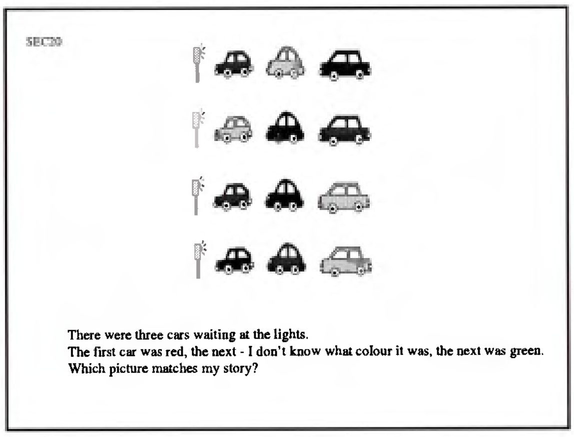
SEC18

There was a caterpillar. The head and shoulders were brown, next - I don't what colour he was,
next he was yellow.
Which picture matches my story?



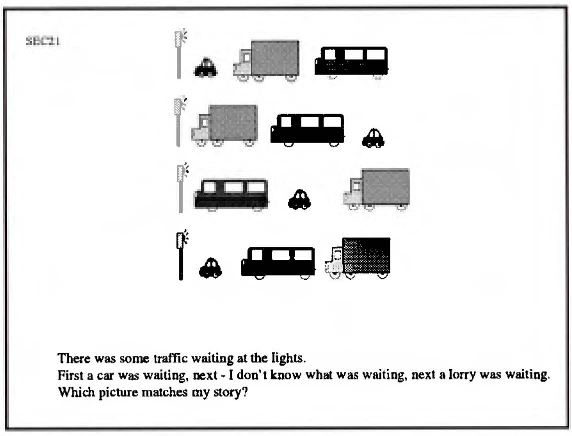
SEC19

There were three beads on a string.
First I put on a square bead, next - I don't know, next a round bead.
Which picture matches my story?



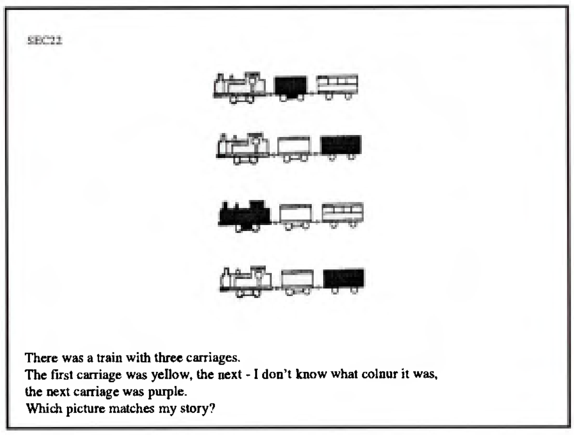
SEC20

There were three cars waiting at the lights.
The first car was red, the next - I don't know what colour it was, the next was green.
Which picture matches my story?



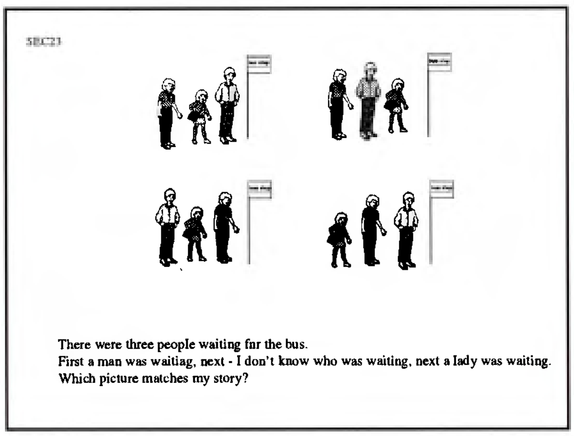
SEC21

There was some traffic waiting at the lights.
First a car was waiting, next - I don't know what was waiting, next a lorry was waiting.
Which picture matches my story?



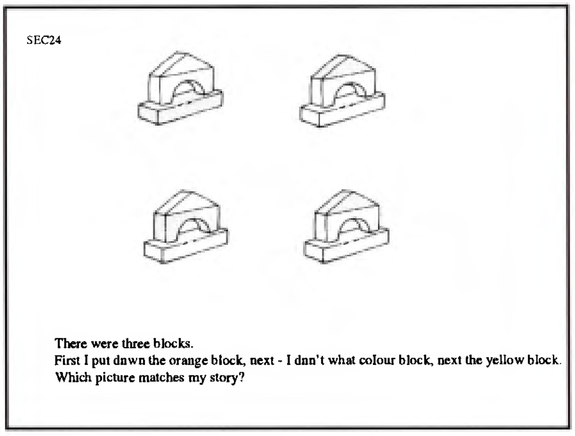
SEC22

There was a train with three carriages.
The first carriage was yellow, the next - I don't know what colnur it was,
the next carriage was purple.
Which picture matches my story?



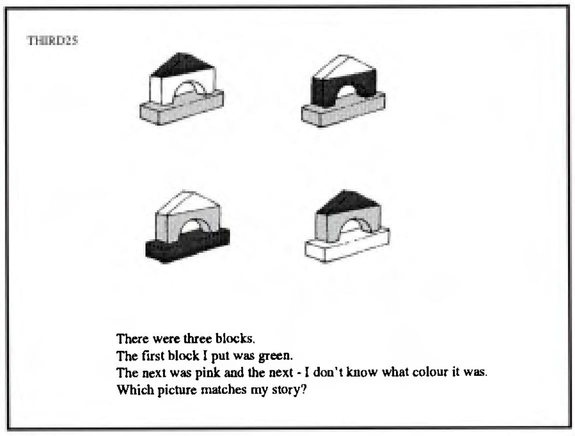
SEC23

There were three people waiting fnr the bus.
First a man was waitiag, next - I don't know who was waiting, next a lady was waiting.
Which picture matches my story?



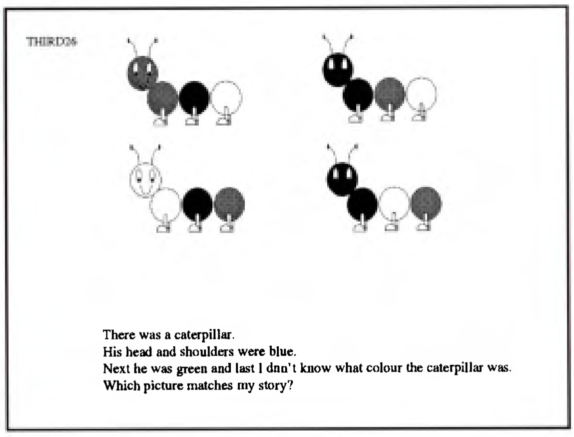
SEC24

There were three blocks.
First I put dnwn the orange block, next - I dnn't what colour block, next the yellow block.
Which picture matches my story?



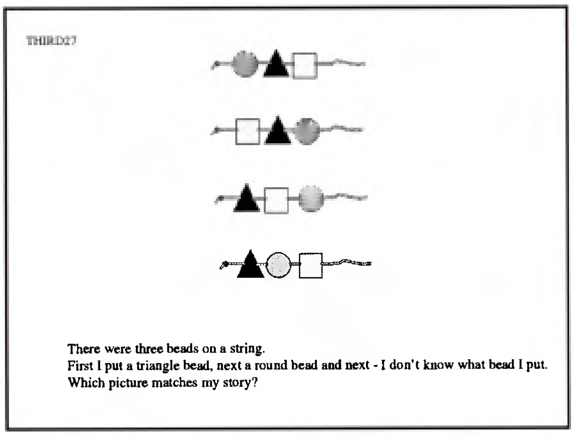
THIRD25

There were three blocks.
The first block I put was green.
The next was pink and the next - I don't know what colour it was.
Which picture matches my story?



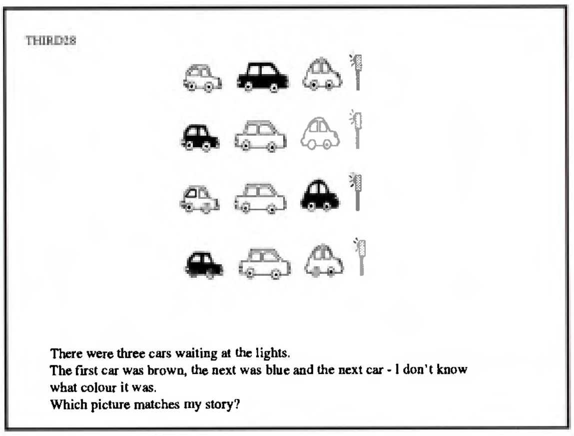
THIRD26

There was a caterpillar.
His head and shoulders were blue.
Next he was green and last I don't know what colour the caterpillar was.
Which picture matches my story?



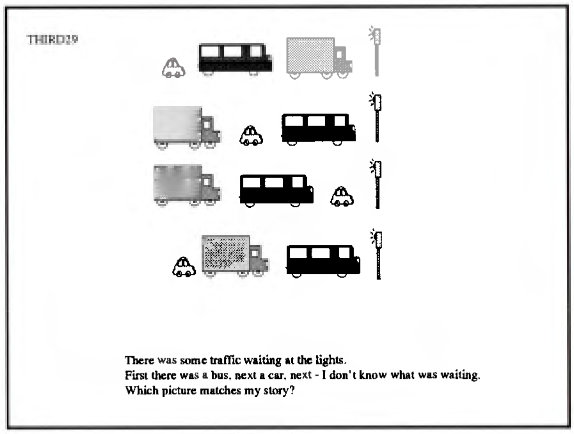
THIRD27

There were three beads on a string.
First I put a triangle bead, next a round bead and next - I don't know what bead I put.
Which picture matches my story?



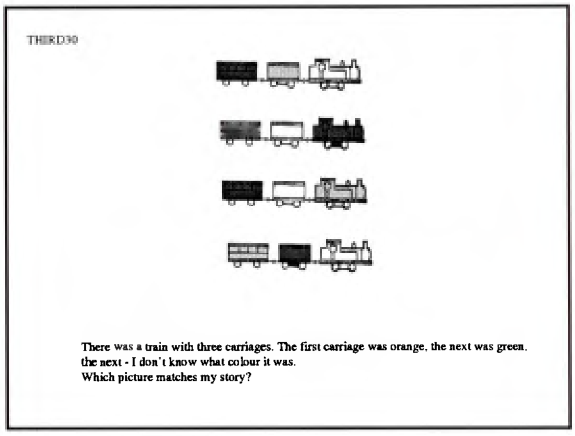
THIRD28

There were three cars waiting at the lights.
The first car was brown, the next was blue and the next car - I don't know what colour it was.
Which picture matches my story?



THIRD29

There was some traffic waiting at the lights.
First there was a bus, next a car, next - I don't know what was waiting.
Which picture matches my story?



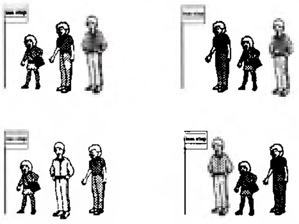
THIRD30

There was a train with three carriages. The first carriage was orange, the next was green.
the next - I don't know what colour it was.
Which picture matches my story?

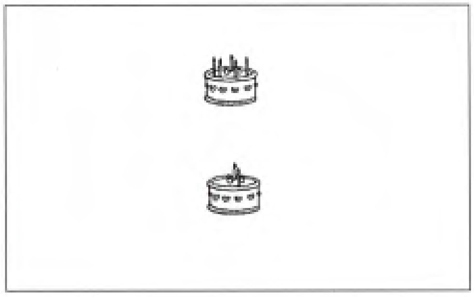
THIRD31

There were three people waiting for a bus. First there was a lady, next
a girl
Then, I don't know who was waiting.
Which picture matches my story?

THIRD32

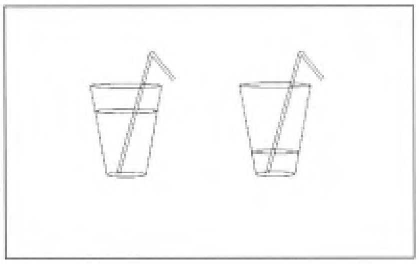


There were three people waiting for the bus.
First a girl was waiting, next a man, next - I don't who was waiting.
Which picture matches my story?



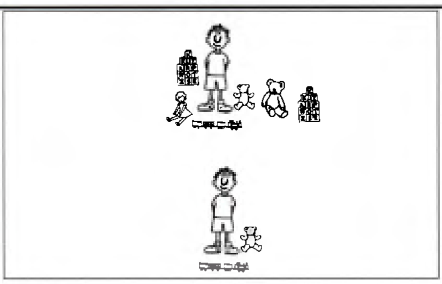
The cake had some candles and then I put some more on.

CHAINC33



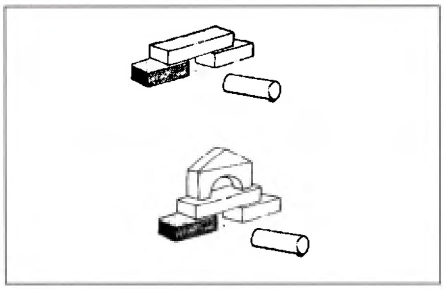
I had some drink in a glass. Then I poured some more in the glass.

CHAINC34



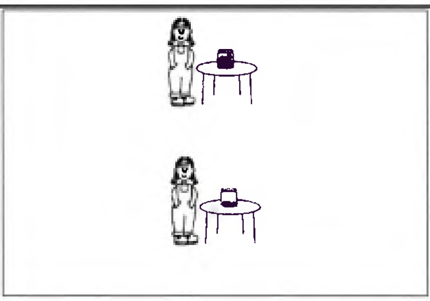
A boy had some toys. Then Daddy gave him some toys.

CHAINC35



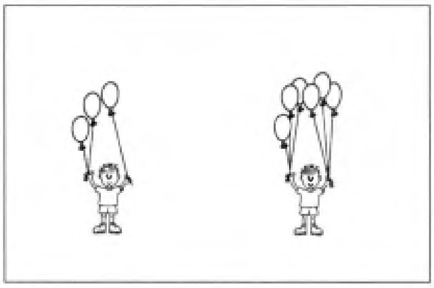
I had some blocks, then I put some more on.

CHAINC36



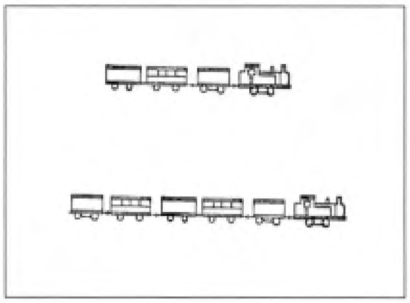
A girl had some sweets, then Mummy gave her some sweets.

CHAINC37



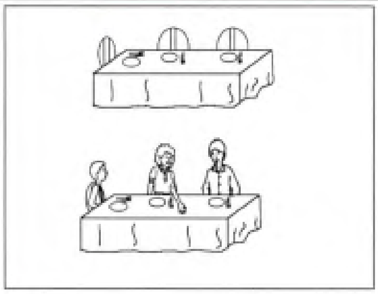
A boy had some balloons, then Mummy gave him some balloons.

CHAINC38



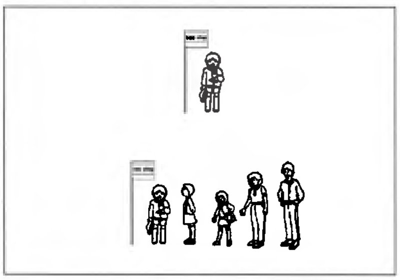
The train had some carriages. Then I put some more on.

CHAINC39



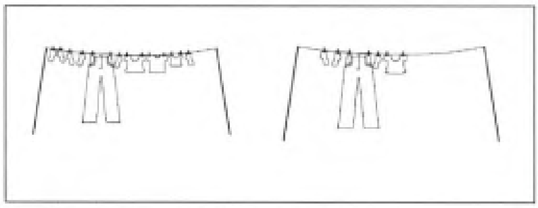
There was a table, then some people sat down.

CHAINC40



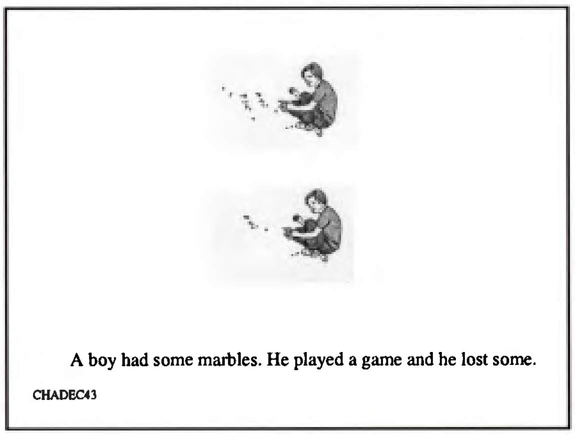
There were some people waiting at the bus stop. A bus came along and some people got on.

CHADEC41



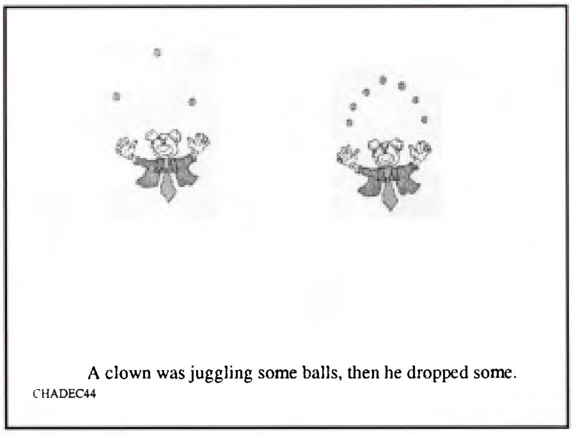
Some clothes were hanging on the line, I went and took some away.

CHADEC42



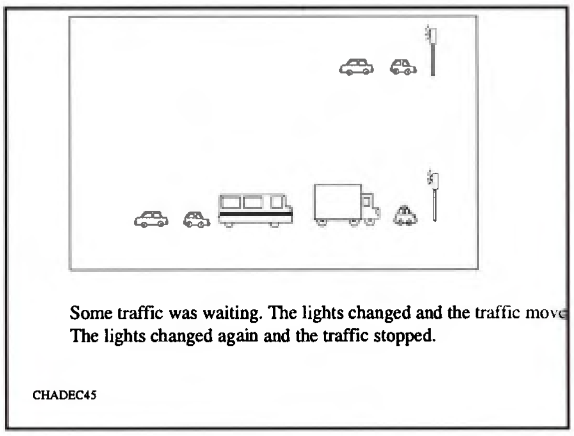
A boy had some marbles. He played a game and he lost some.

CHADEC43



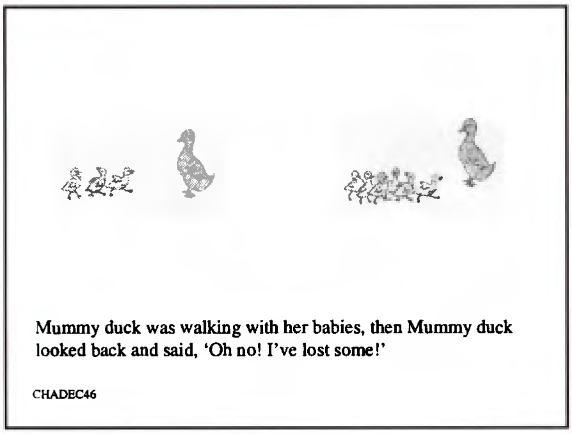
A clown was juggling some balls, then he dropped some.

CHADEC44



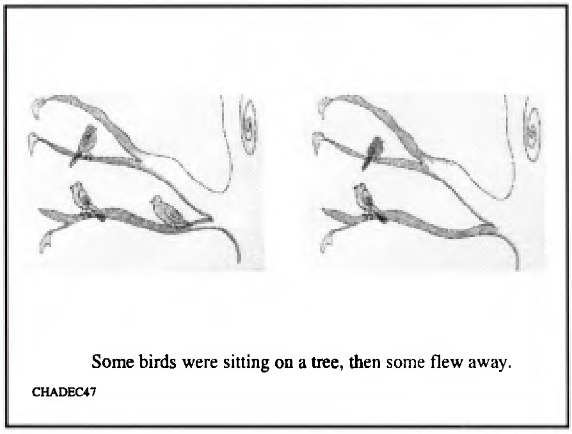
Some traffic was waiting. The lights changed and the traffic mov
The lights changed again and the traffic stopped.

CHADEC45



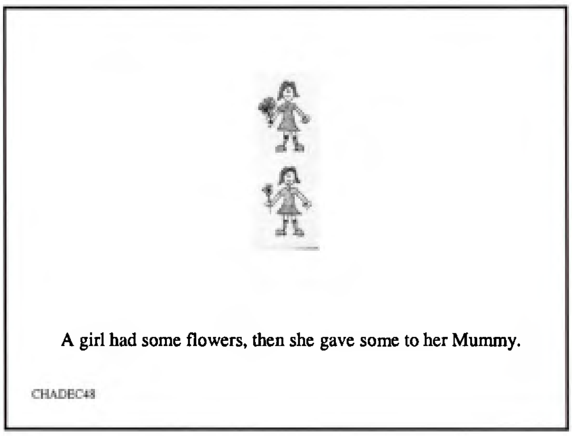
Mummy duck was walking with her babies, then Mummy duck looked back and said, 'Oh no! I've lost some!'

CHADEC46



Some birds were sitting on a tree, then some flew away.

CHADEC47

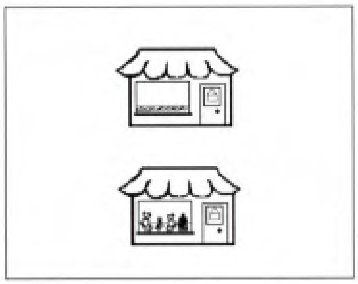


A girl had some flowers, then she gave some to her Mummy.

CHADEC48

Today I went to the shops. Yesterday I went to the woods.

NOM58

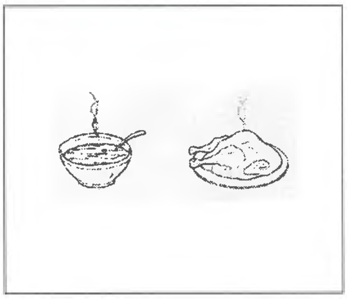


Today I bought toys. Yesterday I bought shoes.

NOM59

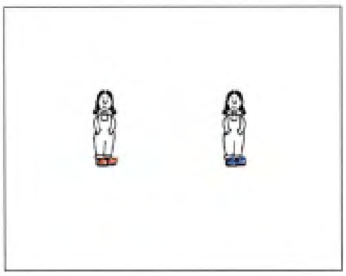
Today I ate a sandwich. Yesterday I ate a burger.

NOM60



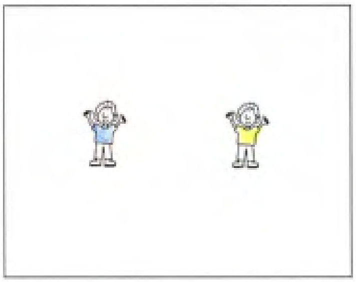
Today I ate chicken. Yesterday I ate soup.

NOM61



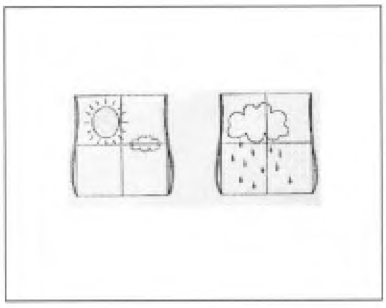
Today the girl had blues shoes on. Yesterday the girl had red shoes on.

NOM62



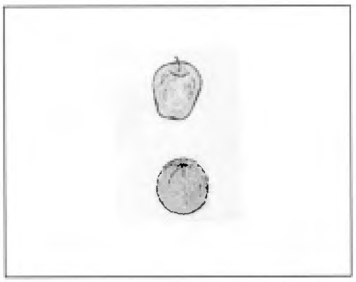
Today the boy wore a yellow t-shirt. Yesterday the boy wore a blue t-shirt.

NOM63

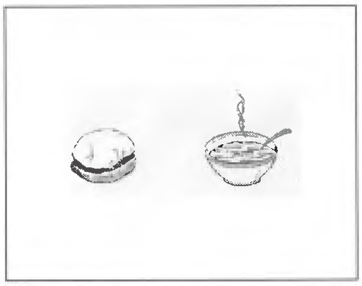


NOM64 Today it is sunny. Yesterday it was raining.

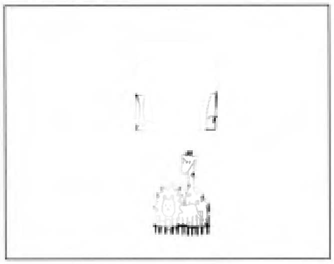
NOM65 Today I played on the skateboard.
Yesterday I played on the swings.



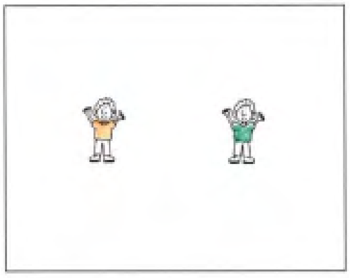
IOM66 Yesterday I ate an apple.
Today I ate an orange.



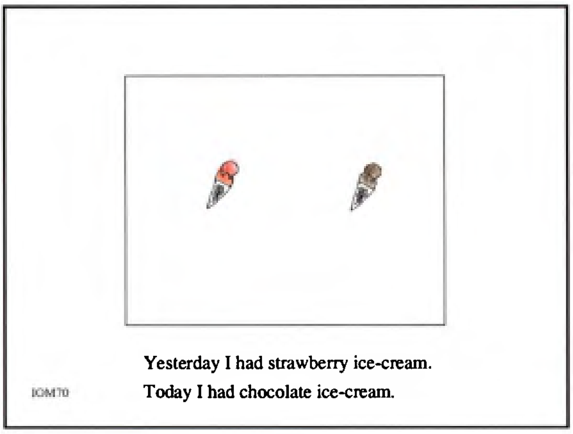
IOM67 Yesterday I ate soup. Today I ate hamburger.



IOM68 Yesterday I went to the zoo. Today I went to the woods.

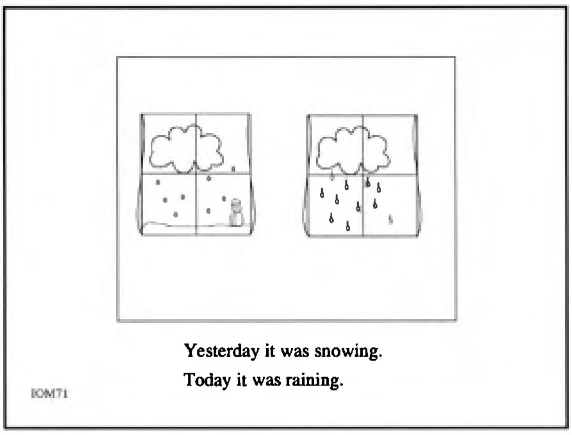


IOM69 Yesterday the boy had an orange t-shirt.
Today the boy had a green t-shirt.



Yesterday I had strawberry ice-cream.
Today I had chocolate ice-cream.

IOM70

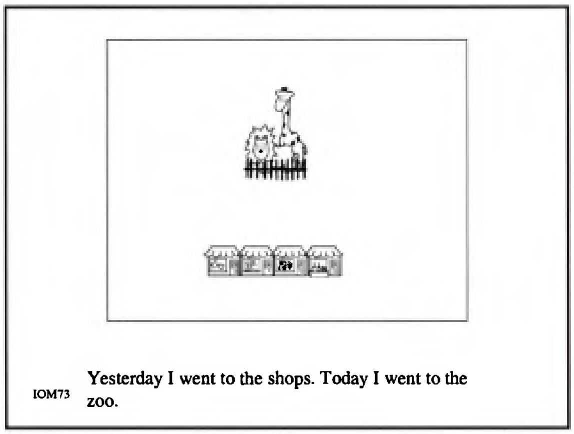


Yesterday it was snowing.
Today it was raining.

IOM71

Yesterday the doll had a pink dress.
Today the doll had a red dress.

IOM72



Yesterday I went to the shops. Today I went to the zoo.

IOM73

Analysis from Chapter 3

Table 1 Analysis of variance of NFER (1) scores by hearing status and year group

Source	**SS**	**DF**	**MS**	**F**
Hearing status	0.08	1	0.08	27.94 ****
Year group	0.05	1	0.05	16.95 ****
Interaction	0.001	1	0.001	0.55 $^{n.s.}$
Residual	0.22	75	0.003	
Total	292.84	78		

Note: Significance of F: * p < .05, ** p < .01, *** p < .001, **** p < .0001, $^{n.s.}$ not significant

Table 2 Analysis of variance of memory accuracy scores by hearing status and SSS

Source	**SS**	**DF**	**MS**	**F**
Between Subjects				
Hearing status	120.34	1	120.34	13.92 ****
Residual	665.90	77	8.65	
Within Subjects				
SSS	253.13	5	50.63	40.19 ****
Residual	484.95	385	1.26	
Hearing status x SSS	18.58	5	3.72	2.95 *

Note: Significance of F: * p < .05, ** p < .01, *** p < .001, **** p < .0001, $^{n.s.}$ not significant

Table 3 Analysis of variance of response time to negative probes by hearing status and SSS

Source	SS	DF	MS	F
Between Subjects				
Hearing status	73.54	1	73.54	11.70 ***
Residual	439.99	70	6.29	
Within Subjects				
SSS	10.36	5	2.07	1.66 n.s.
Residual	437.49	350	1.25	
Hearing status x SSS	4.60	5	0.92	0.74 n.s.

Note: Significance of F: * p < .05, ** p < .01, *** p < .001, **** p < .0001, n.s. not significant

Table 4 Analysis of variance of response time to positive probes by hearing status and SSS

Source	SS	DF	MS	F
Between Subjects				
Hearing status	24.96	1	24.96	5.27 *
Residual	340.89	72	4.73	
Within Subjects				
SSS	10.97	5	2.19	0.03 n.s.
Residual	306.37	360	0.85	
Hearing status x SSS	1.43	5	0.34	0.34 n.s.

Note: Significance of F: * p < .05, ** p < .01, *** p < .001, **** p < .0001, n.s. not significant

Table 5 Percentage of hearing impaired children giving correct responses to NP-HR task by item

Item	Percentage correct	Item	Percentage correct
ALL1	55.8	THIRD25	62.8
ALL2	81.4	THIRD26	79.1
ALL3	79.1	THIRD27	62.8
ALL4	86.0	THIRD28	86.0
ALL5	32.6	THIRD29	79.1
ALL6	60.5	THIRD30	81.4
ALL7	72.1	THIRD31	67.4
ALL8	60.5	THIRD32	72.1

Table 6 Percentage of hearing impaired children giving correct responses to P-HR task by item

Item	Percentage correct	Item	Percentage correct
FIRST9	51.2	SECOND17	39.5
FIRST10	41.9	SECOND18	60.5
FIRST11	53.5	SECOND19	67.4
FIRST12	62.8	SECOND20	55.8
FIRST13	41.9	SECOND21	44.2
FIRST14	51.2	SECOND22	60.5
FIRST15	37.2	SECOND23	67.4
FIRST16	62.8	SECOND24	55.8

Table 7 Percentage of hearing impaired children giving correct responses to Change task by item

Item	Percentage correct	Item	Percentage correct
CHANGEINC33	37.2	CHANGEDEC41	51.2
CHANGEINC34	58.1	CHANGEDEC42	67.4
CHANGEINC35	48.8	CHANGEDEC43	67.4
CHANGEINC36	51.2	CHANGEDEC44	72.1
CHANGEINC37	41.9	CHANGEDEC45	62.8
CHANGEINC38	48.8	CHANGEDEC46	65.1
CHANGEINC39	48.8	CHANGEDEC47	72.1
CHANGEINC40	41.9	CHANGEDEC48	65.1

Table 8 Percentage of hearing impaired children giving correct responses to Inversion task by item

Item	Percentage correct	Item	Percentage correct
IOM66	69.8	NOM58	14.0
IOM67	72.1	NOM59	27.9
IOM68	81.4	NOM60	23.3
IOM69	76.7	NOM61	27.9
IOM70	76.7	NOM62	37.2
IOM71	76.7	NOM63	23.3
IOM72	62.8	NOM64	11.6
IOM73	76.7	NOM65	25.6

Table 9 Percentage of hearing children giving correct responses to NP-HR task by item

Item	Percentage correct	Item	Percentage correct
ALL2	83.8	THIRD27	75.7
ALL3	78.4	THIRD28	78.4
ALL4	97.3	THIRD29	81.1
ALL5	16.2	THIRD32	78.2

Table 10 Percentage of hearing children giving correct responses to P-HR task by item

Item	Percentage correct	Item	Percentage correct
FIRST9	73.0	SECOND17	67.6
FIRST10	54.1	SECOND22	91.9
FIRST11	59.5	SECOND23	70.3
FIRST12	78.4	SECOND24	64.9

Table 11 Percentage of hearing children giving correct responses to the Change task by item

Item	Percentage correct	Item	Percentage correct
CHANGEINC33	75.7	CHANGEDEC41	73.0
CHANGEINC35	91.9	CHANGEDEC43	94.6
CHANGEINC36	86.5	CHANGEDEC45	51.4
CHANGEINC40	94.6	CHANGEDEC48	94.6

Table 12 Percentage of hearing children giving correct responses to the Inversion task by item

Item	Percentage correct	Item	Percentage correct
IOM66	89.2	NOM60	32.4
IOM67	94.6	NOM61	40.5
IOM70	91.9	NOM64	18.9
IOM72	91.9	NOM65	27.0

Analysis from Chapter 4

Table 1 Summary of one-way Analysis of variance of NFER (1) scores by School

Source	**DF**	**SS**	**MS**	**F**
Between groups	6	0.01	0.02	0.49 $^{n.s.}$
Within groups	35	0.14	0.04	
Total	41	0.15		

Note: Significance of F: * p < .05, ** p < .01, *** p < .001, **** p < .0001, n.s. not significant

Table 2 Summary of one-way Analysis of variance of Number Age scores by School

Source	**DF**	**SS**	**MS**	**F**
Between groups	6	998.91	166.49	0.92 $^{n.s.}$
Within groups	34	6137.53	180.52	
Total	40	7136.44		

Note: Significance of F: * p < .05, ** p < .01, *** p < .001, **** p < .0001, n.s. not significant

Table 3 Summary of one-way Analysis of variance of NFER(3) scores by School

Source	**DF**	**SS**	**MS**	**F**
Between groups	6	0.03	0.05	0.99 $^{n.s.}$
Within groups	34	0.16	0.05	
Total	40	0.19		

Note: Significance of F: * p < .05, ** p < .01, *** p < .001, **** p < .0001, n.s. not significant

Table 4 Summary of one-way Analysis of variance of NFER (1) scores by Signing status

Source	**DF**	**SS**	**MS**	**F**
Between groups	2	0.002	0.001	0.30 $^{n.s.}$
Within groups	39	0.15	0.004	
Total	41	0.15		

Note: Significance of F: * p < .05, ** p < .01, *** p < .001, **** p < .0001, n.s. not significant

Table 5 Summary of one-way Analysis of variance of Number Age scores by Signing status

Source	DF	SS	MS	F
Between groups	2	24.85	12.42	0.07 n.s.
Within groups	38	7111.59	187.15	
Total	40	7136.44		

Note: Significance of F: * p < .05, ** p < .01, *** p < .001, **** p < .0001, n.s. not significant

Table 6 Summary of one-way Analysis of variance of NFER (3) scores by Signing status

Source	DF	SS	MS	F
Between groups	2	0.003	0.02	0.35 n.s.
Within groups	38	0.19	0.05	
Total	40	0.19		

Note: Significance of F: * p < .05, ** p < .01, *** p < .001, **** p < .0001, n.s. not significant

Table 7 Correlation (Spearman's rho) matrix of NFER(1) scores with tasks used as predictor variables

	WISC-III	MIRA	CELF (OD)	CELF (SS)	Memory capacity	Counting to highest	Counting backward	Shop Task	Place holders	Change
NFER (1)	.38 (41) *.02*	.47 (41) *.002*	.44 (40) >*.005*	.39 (40) *.01*	.35 (41) *.02*	.36 (41) *.02*	.49 (41) *.001*	.63 (41) >*.001*	.54 (41) >*.001*	.49 (41) *.001*
WISC-III		.28 (41) *.08*	.37 (40) *.02*	.42 (40) *.01*	.47 (41) *.002*	.40 (41) *.01*	.43 (41) *.01*	.51 (41) *.001*	.58 (41) >*.001*	.27 (41) *.09*
MIRA			.58 (40) <*.001*	.52 (40) *.001*	.48 (41) *.001*	.58 (41) >*.001*	.41 (41) *.01*	.72 (41) <*.001*	.56 (41) >*.001*	.60 (41) >*.001*
CELF (OD)				.45 (40) *.004*	.61 (40) <*.001*	.37 (40) *.02*	.19 (40) *.25*	.68 (40) <*.001*	.48 (40) *.002*	.41 (40) *.01*
CELF (SS)					.39 (40) *.01*	.23 (40) .15	.23 (40) *.15*	.41 (40) *.01*	.35 (40) *.03*	.43 (40) *.005*
Memory capacity						.49 (41) *.001*	.30 (41) *.06*	.49 (41) *.001*	.35 (41) *.03*	.18 (41) *.27*
Counting to highest							.39 (41) *.01*	.54 (41) <*.001*	.52 (41) *.001*	.27 (41) .08
Counting backwards								.38 (41) *.02*	.56 (41) >*.001*	.33 (41) *.04*
Shop Task									.71 (41) <*.001*	.53 (41) >*.001*
Place-holders										.59 (41) >*.001*

Table 8 Correlation (Spearman's rho) matrix of Number age scores with tasks used as predictor variables

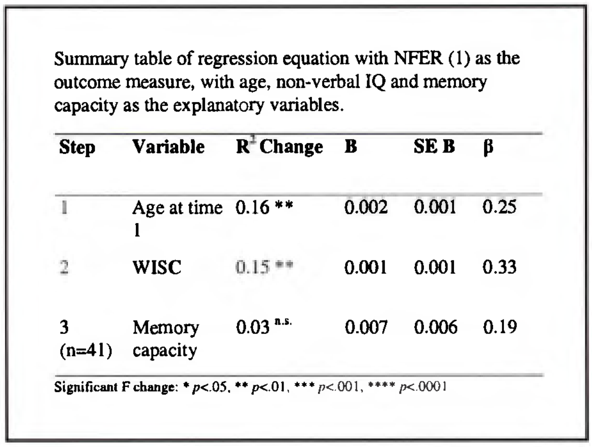
	WISC-III	MIRA	CELF (OD)	CELF (SS)	Memory capacity	Counting to highest	Counting backward	Shop Task	Place holders	Change
Number Age	.64 (40) *<.001*	.57 (40) *<.001*	.42 (39) *.01*	.42 (39) *.01*	.60 (40) *>.001*	.58 (40) *<.001*	.58 (40) *<.001*	.74 (40) *<.001*	.72 (40) *<.001*	.46 (40) *.003*
WISC-III		.28 (41) *.08*	.37 (40) *.02*	.42 (40) *.01*	.47 (41) *.002*	.40 (41) *.01*	.43 (41) *.01*	.51 (41) *.001*	.58 (41) *>.001*	.27 (41) *.09*
MIRA			.58 (40) *<.001*	.52 (40) *.001*	.48 (41) *.001*	.58 (41) *>.001*	.41 (41) *.01*	.72 (41) *<.001*	.56 (41) *>.001*	.60 (41) *>.001*
CELF (OD)				.45 (40) *.004*	.61 (40) *<.001*	.37 (40) *.02*	.19 (40) *.25*	.68 (40) *<.001*	.48 (40) *.002*	.41 (40) *.01*
CELF (SS)					.39 (40) *.01*	.23 (40) .15	.23 (40) *.15*	.41 (40) *.01*	.35 (40) *.03*	.43 (40) *.005*
Memory capacity						.49 (41) *.001*	.30 (41) *.06*	.49 (41) *.001*	.35 (41) *.03*	.18 (41) *.27*
Counting to highest							.39 (41) *.01*	.54 (41) *<.001*	.52 (41) *.001*	.27 (41) .08
Counting backwards								.38 (41) *.02*	.56 (41) *>.001*	.33 (41) *.04*
Shop Task									.71 (41) *<.001*	.53 (41) *>.001*
Place-holders										.59 (41) *>.001*

Table 9 Correlation (Spearman's rho) matrix of NFER(3) scores with tasks used as predictor variables

	WISC-III	MIRA	CELF (OD)	CELF (SS)	Memory capacity	Counting to highest	Counting backward	Shop Task	Place holders	Change
NFER (3)	.51 (40) *.001*	.60 (40) *<.001*	.60 (40) *<.001*	.51 (40) *.001*	.40 (40) *.01*	.43 (40) *.01*	.40 (40) *.01*	.65 (40) *<.001*	.64 (40) *<.001*	.62 (40) *<.001*
WISC-III		.28 (41) *.08*	.37 (40) *.02*	.42 (40) *.01*	.47 (41) *.002*	.40 (41) *.01*	.43 (41) *.01*	.51 (41) *.001*	.58 (41) *>.001*	.27 (41) *.09*
MIRA			.58 (40) *<.001*	.52 (40) *.001*	.48 (41) *.001*	.58 (41) *>.001*	.41 (41) *.01*	.72 (41) *<.001*	.56 (41) *>.001*	.60 (41) *>.001*
CELF (OD)				.45 (40) *.004*	.61 (40) *<.001*	.37 (40) *.02*	.19 (40) *.25*	.68 (40) *<.001*	.48 (40) *.002*	.41 (40) *.01*
CELF (SS)					.39 (40) *.01*	.23 (40) .15	.23 (40) *.15*	.41 (40) *.01*	.35 (40) *.03*	.43 (40) *.005*
Memory capacity						.49 (41) *.001*	.30 (41) *.06*	.49 (41) *.001*	.35 (41) *.03*	.18 (41) *.27*
Counting to highest							.39 (41) *.01*	.54 (41) *<.001*	.52 (41) *.001*	.27 (41) .08
Counting backwards								.38 (41) *.02*	.56 (41) *>.001*	.33 (41) *.04*
Shop Task									.71 (41) *<.001*	.53 (41) *>.001*
Place-holders										.59 (41) *>.001*

Summary tables and residual plots for regression analyses carried out in Chapter 4

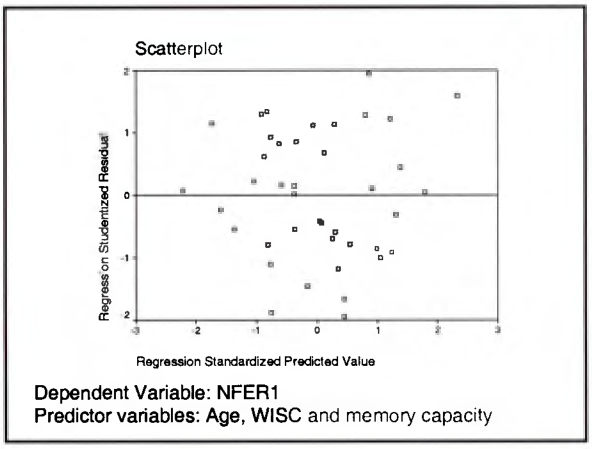
Note: The following summaries are presented in the following order for convenience. The summary table of the regression equation is found on the left hand column and the corresponding residual plot is adjacent in the right hand column.



Summary table of regression equation with NFER (1) as the outcome measure, with age, non-verbal IQ and memory capacity as the explanatory variables.

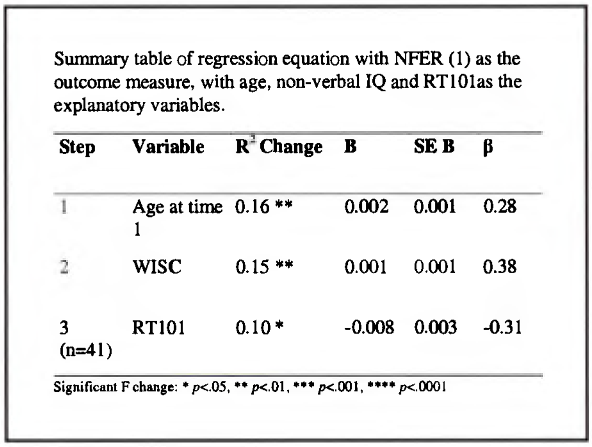
Step	Variable	R^2 Change	B	SE B	β
1	Age at time 1	0.16 **	0.002	0.001	0.25
2	WISC	0.15 **	0.001	0.001	0.33
3 (n=41)	Memory capacity	0.03 $^{n.s.}$	0.007	0.006	0.19

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$



Scatterplot

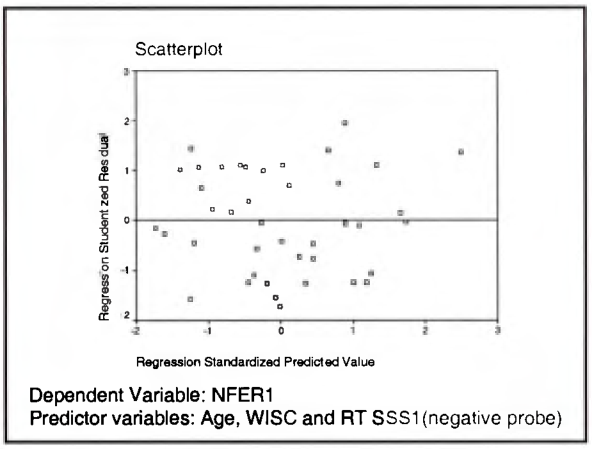
Dependent Variable: NFER1
Predictor variables: Age, WISC and memory capacity



Summary table of regression equation with NFER (1) as the outcome measure, with age, non-verbal IQ and RT101as the explanatory variables.

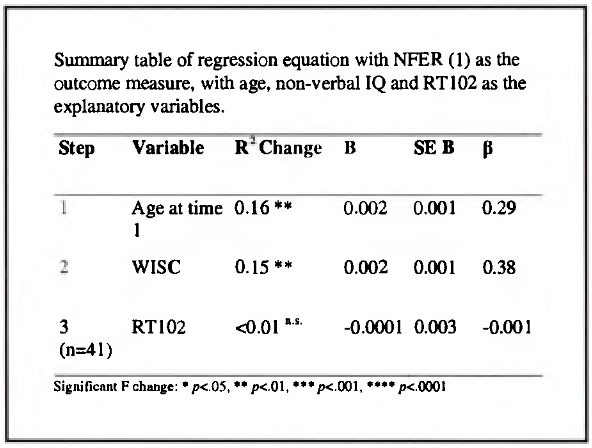
Step	Variable	R^2 Change	B	SE B	β
1	Age at time 1	0.16 **	0.002	0.001	0.28
2	WISC	0.15 **	0.001	0.001	0.38
3 (n=41)	RT101	0.10 *	-0.008	0.003	-0.31

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$



Scatterplot

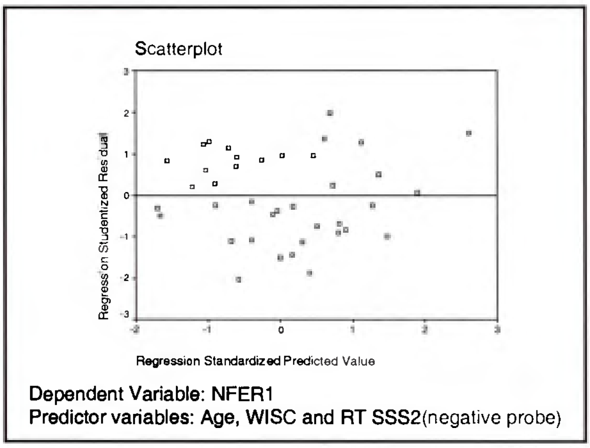
Dependent Variable: NFER1
Predictor variables: Age, WISC and RT SSS1(negative probe)



Summary table of regression equation with NFER (1) as the outcome measure, with age, non-verbal IQ and RT102 as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 1	0.16 **	0.002	0.001	0.29
2	WISC	0.15 **	0.002	0.001	0.38
3 (n=41)	RT102	<0.01 $^{n.s.}$	-0.0001	0.003	-0.001

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$



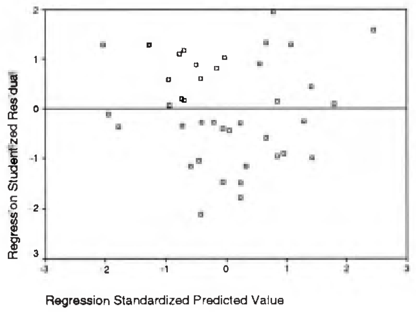
Scatterplot

Dependent Variable: NFER1
Predictor variables: Age, WISC and RT SSS2(negative probe)

Summary table of regression equation with NFER (1) as the outcome measure, with age, non-verbal IQ and RT103 as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 1	0.16 **	0.002	0.001	0.29
2	WISC	0.15 **	0.001	0.001	0.33
3 (n=41)	RT103	0.01 $^{\text{n.s.}}$	-0.003	0.004	-0.13

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$

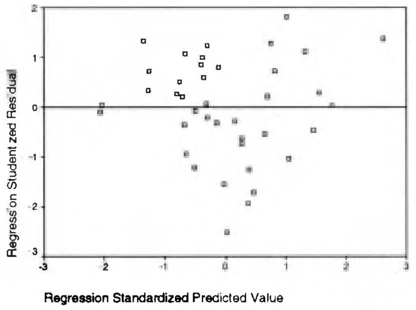


Dependent Variable: NFER1
Predictor variables: Age, WISC and RT SSS3(negative probe)

Summary table of regression equation with NFER (1) as the outcome measure, with age, non-verbal IQ and RT104 as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 1	0.16 **	0.002	0.001	0.22
2	WISC	0.15 **	0.001	0.001	0.38
3 (n=41)	RT104	0.05 $^{\text{n.s.}}$	-0.01	0.007	-0.23

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$

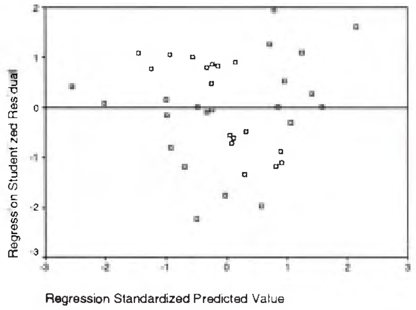


Dependent Variable: NFER1
Predictor variables: Age, WISC and RT SSS4(negative probe)

Summary table of regression equation with NFER (1) as the outcome measure, with age, non-verbal IQ and RT105 as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 1	0.16 **	0.002	0.001	0.26
2	WISC	0.15 **	0.001	0.001	0.27
3 (n=41)	RT105	0.07 $^{\text{n.s.}}$	-0.01	0.006	-0.30

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$

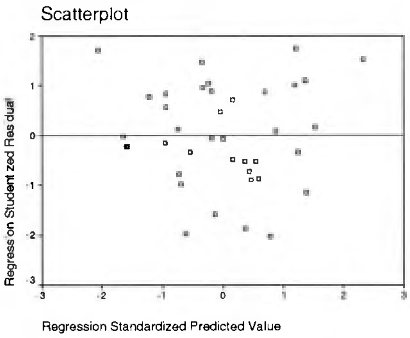


Dependent Variable: NFER1
Predictor variables: Age, WISC and RT SSS5(negative probe)

Summary table of regression equation with NFER (1) as the outcome measure, with age, non-verbal IQ and RT106 as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 1	0.16 **	0.001	0.001	0.14
2	WISC	0.15 **	0.002	0.001	0.46
3 (n=41)	RT106	0.11 *	-0.01	0.004	-0.36

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$

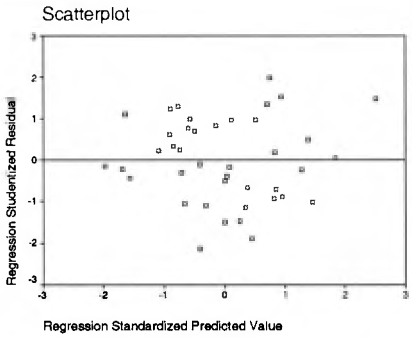


Dependent Variable: NFER1
Predictor variables: Age, WISC and RT SSS6(negative probe)

Summary table of regression equation with NFER (1) as the outcome measure, with age, non-verbal IQ and RT111 as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 1	0.16 **	0.002	0.001	0.28
2	WISC	0.15 **	0.001	0.001	0.39
3 (n=41)	RT111	<0.01 $^{n.s.}$	-0.002	0.007	-0.05

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$

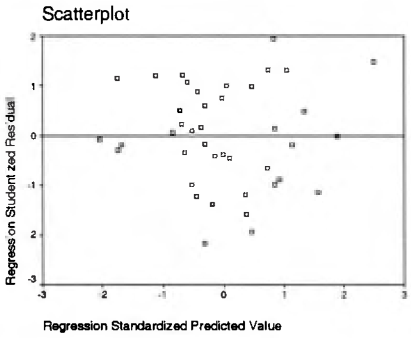


Dependent Variable: NFER1
Predictor variables: Age, WISC and RT SSS1(positive probe)

Summary table of regression equation with NFER (1) as the outcome measure, with age, non-verbal IQ and RT112 as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 1	0.16 **	0.002	0.001	0.25
2	WISC	0.15 **	0.001	0.001	0.37
3 (n=41)	RT112	0.02 $^{n.s.}$	-0.005	0.005	-0.14

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$



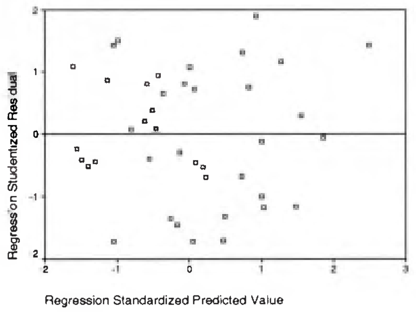
Dependent Variable: NFER1
Predictor variables: Age, WISC and RT SSS2(positive probe)

Summary table of regression equation with NFER (1) as the outcome measure, with age, non-verbal IQ and RT113 as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 1	0.16 **	0.002	0.001	0.28
2	WISC	0.15 **	0.001	0.001	0.34
3 (n=41)	RT113	0.05 $^{n.s.}$	-0.008	0.004	-0.32

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$

Scatterplot



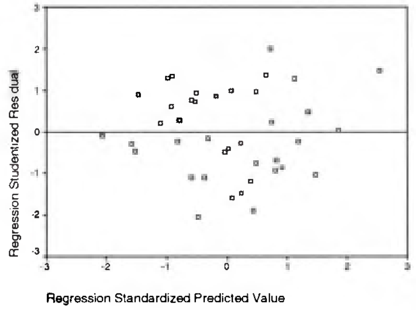
Dependent Variable: NFER1
Predictor variables: Age, WISC and RT SSS3(positive probe)

Summary table of regression equation with NFER (1) as the outcome measure, with age, non-verbal IQ and RT114 as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 1	0.16 **	0.002	0.001	0.28
2	WISC	0.15 **	0.002	0.001	0.40
3 (n=41)	RT114	<0.01 $^{n.s.}$	-0.0005	0.005	-0.02

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$

Scatterplot



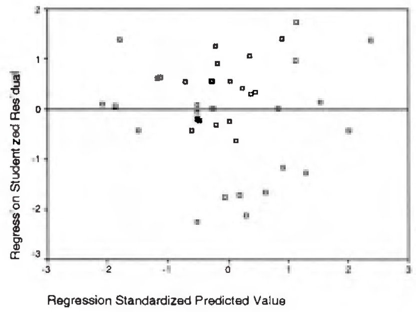
Dependent Variable: NFER1
Predictor variables: Age, WISC and RT SSS4(positive probe)

Summary table of regression equation with NFER (1) as the outcome measure, with age, non-verbal IQ and RT115 as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 1	0.16 **	0.001	0.001	0.11
2	WISC	0.15 **	0.002	0.001	0.42
3 (n=41)	RT115	0.11 *	-0.02	0.007	-0.36

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$

Scatterplot

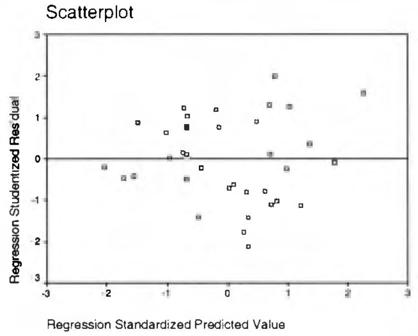


Dependent Variable: NFER1
Predictor variables: Age, WISC and RT SSS5(positive probe)

Summary table of regression equation with NFER (1) as the outcome measure, with age, non-verbal IQ and RT116 as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 1	0.16 **	0.002	0.001	0.26
2	WISC	0.15 **	0.001	0.001	0.42
3 (n=41)	RT116	<0.01 $^{n.s.}$	-0.004	0.008	-0.09

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$

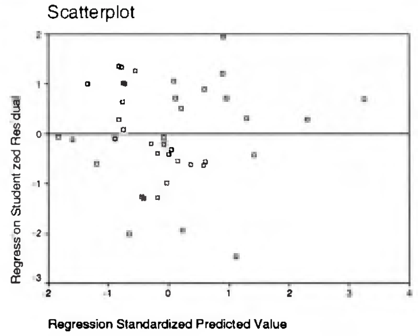


Dependent Variable: NFER1
Predictor variables: Age, WISC and RT SSS6(positive probe)

Summary table of regression equation with NFER (1) as the outcome measure, with age, non-verbal IQ and MIRA as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 1	0.16 **	0.001	0.001	0.13
2	WISC	0.15 **	0.001	0.001	0.31
3 (n = 41)	MIRA	0.11 **	0.008	0.003	0.39

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$

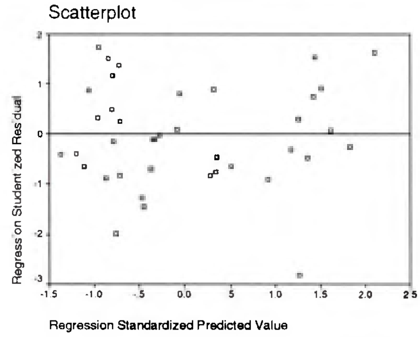


Dependent Variable: NFER1
Predictor variables: Age, WISC and MIRA

Summary table of regression equation with NFER (1) as the outcome measure, with age, non-verbal IQ and Shop Task as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 1	0.16 **	0.001	0.001	0.10
2	WISC	0.15 **	0.001	0.001	0.21
3 (n = 41)	Shop Task	0.17**	0.03	0.009	0.51

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$



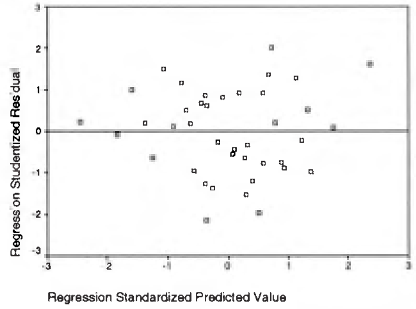
Dependent Variable: NFER1
Predictor variables: Age, WISC and Shop Task

Summary table of regression equation with NFER (1) as the outcome measure, with age, non-verbal IQ and Count high as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time	0.16 **	0.002	0.001	0.27
2	WISC	0.15 **	0.001	0.001	0.35
3 (n=41)	Count high	0.01 $^{n.s.}$	0.001	0.001	0.13

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$

Scatterplot



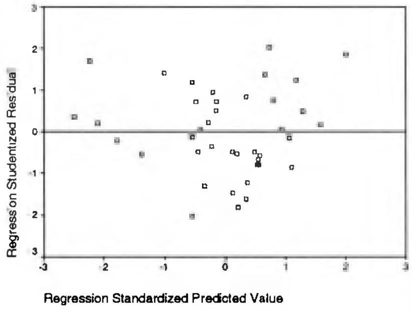
Dependent Variable: NFER1
Predictor variables: Age, WISC and Count high

Summary table of regression equation with NFER (1) as the outcome measure, with age, non-verbal IQ and Count back as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 1	0.16 **	0.002	0.001	0.28
2	WISC	0.15 **	0.001	0.001	0.25
3 (n=41)	Count back	0.05 $^{n.s.}$	0.02	0.009	0.27

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$

Scatterplot



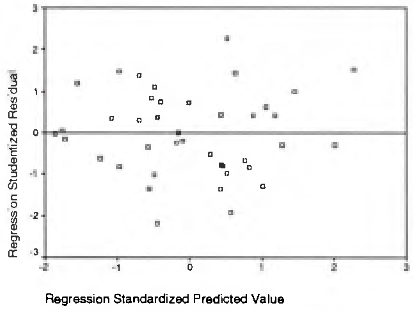
Dependent Variable: NFER1
Predictor variables: Age, WISC and Count back

Summary table of regression equation with NFER (1) as the outcome measure, with age, non-verbal IQ and P-HR as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 1	0.16 **	0.002	0.001	0.21
2	WISC	0.15 **	0.001	0.001	0.18
3 (n=41)	Corrected PH-R	0.11 *	0.004	0.002	0.42

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$

Scatterplot

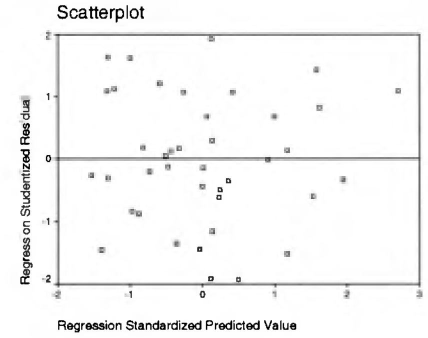


Dependent Variable: NFER1
Predictor variables: Age, WISC and corrected P-HR

Summary table of regression equation with NFER (1) as the outcome measure, with age, non-verbal IQ and Corrected Change as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 1	0.16 **	0.001	0.001	0.19
2	WISC	0.15 **	0.001	>0.001	0.32
3 (n=41)	Corrected Change	0.15 **	0.003	0.001	0.41

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$

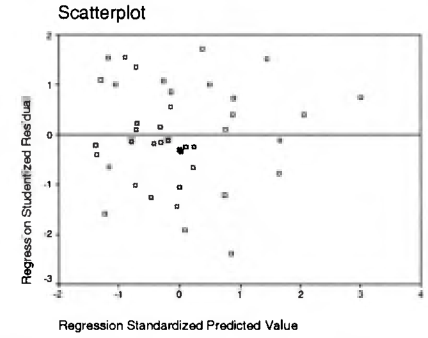


Dependent Variable: NFER1
Predictor variables: Age, WISC and Corrected Change

Summary table of regression equation with NFER (1) as the outcome measure, with age, non-verbal IQ, MIRA and Corrected Change as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 1	0.16 ***	0.001	0.001	0.13
2	WISC	0.15 ***	0.001	0.001	0.29
3	MIRA	0.11 **	0.004	0.003	0.20
4 (n = 41)	Corrected Change	0.06 *	0.003	0.001	0.31

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$

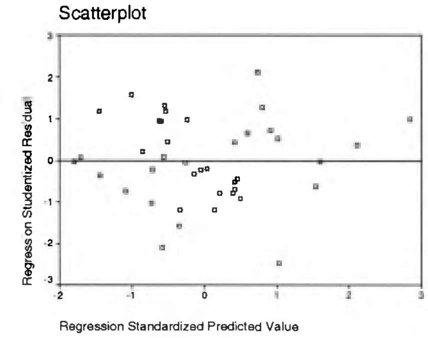


Dependent Variable: NFER1
Predictor variables: Age, WISC, MIRA and Corrected Change

Summary table of regression equation with NFER (1) as the outcome measure, with age, non-verbal IQ, MIRA and corrected P-HR as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 1	0.16 ***	0.001	0.001	0.12
2	WISC	0.15 ***	0.001	0.001	0.19
3	MIRA	0.11 **	0.005	0.003	0.27
4 (n = 41)	Corrected P-HR	0.04 $^{n.s.}$	0.002	0.002	0.29

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$

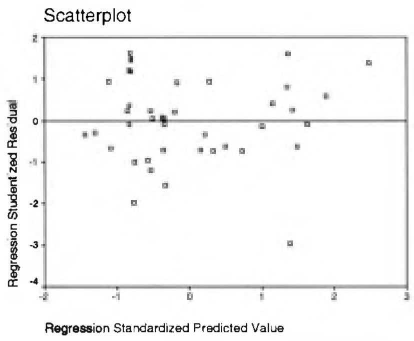


Dependent Variable: NFER1
Predictor variables: Age, WISC, MIRA and Corrected P-HR

Summary table of regression equation with NFER (1) as the outcome measure, with age, non-verbal IQ, MIRA and Shop Task (2 categories) as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 1	0.16 ***	0.001	0.001	0.07
2	WISC	0.15 ***	0.001	0.001	0.21
3	MIRA	0.11 **	0.003	0.003	0.16
4 (n =41)	Shop Task	0.07 *	0.03	0.01	0.41

Significant F change: * *p*<.05, ** *p*<.01, *** *p*<.001, **** *p*<.0001

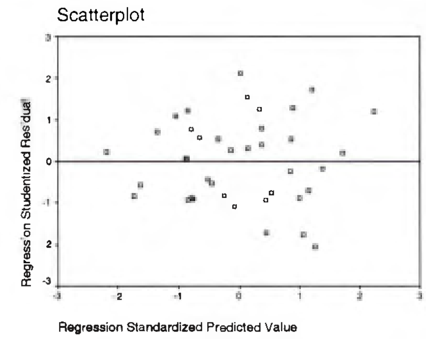


Dependent Variable: NFER1
Predictor variables: Age, WISC, MIRA and Shop task

Summary table of regression equation with Number age as the outcome measure, with age, non-verbal IQ and Memory capacity as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 2	.29 ***	.56	.19	.32
2	WISC	.29 ***	.39	.10	.44
3 (n = 40)	Memory capacity	.07 *	2.48	.95	.30

Significant F change: * *p*<.05, ** *p*<.01, *** *p*<.001, **** *p*<.0001

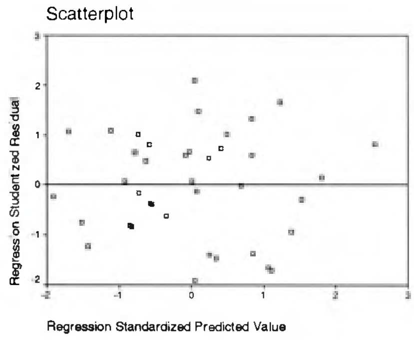


Dependent Variable: Number Age
Predictor variables: Age, WISC and Memory capacity

Summary table of regression equation with Number age as the outcome measure, with age, non-verbal IQ and RT101as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 2	0.29 ****	0.66	0.19	0.37
2	WISC	0.29 ****	0.48	0.10	0.55
3 (n=40)	RT101	0.03 ns	-1.02	0.63	-0.17

Significant F change: * *p*<.05, ** *p*<.01, *** *p*<.001, **** *p*<.0001

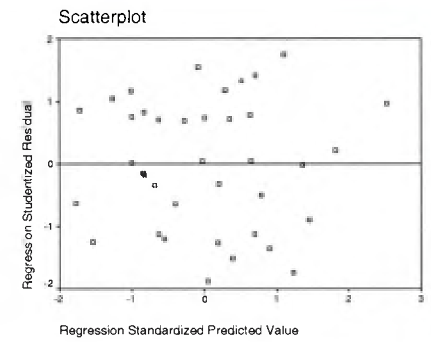


Dependent Variable: Number age
Predictor variables: Age, WISC and RT SSS1(negative probe)

Summary table of regression equation with Number age as the outcome measure, with age, non-verbal IQ and RT102 as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 2	0.29 ****	0.66	0.21	0.38
2	WISC	0.29 ****	0.49	0.11	0.54
3 (n=40)	RT102	<0.01 $^{n.s.}$	-0.05	0.54	-0.01

Significant F change: * p<.05, ** p<.01, *** p<.001, **** p<.0001

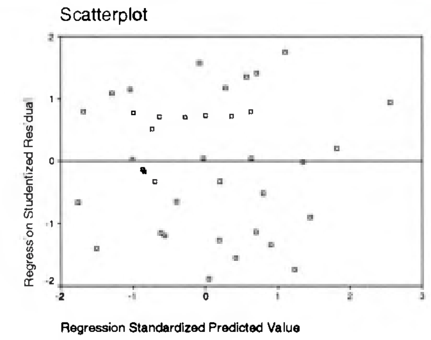


Dependent Variable: Number age
Predictor variables: Age, WISC and RT SSS2(negative probe)

Summary table of regression equation with Number age as the outcome measure, with age, non-verbal IQ and RT103 as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 2	0.29 ****	0.66	0.21	0.39
2	WISC	0.29 ****	0.49	0.12	0.54
3 (n=40)	RT103	<0.01 $^{n.s.}$	0.04	0.78	0.01

Significant F change: * p<.05, ** p<.01, *** p<.001, **** p<.0001

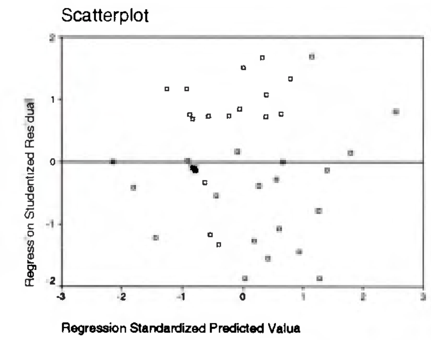


Dependent Variable: Number age
Predictor variables: Age, WISC and RT SSS3(negative probe)

Summary table of regression equation with Number age as the outcome measure, with age, non-verbal IQ and RT104 as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 2	0.29 ****	0.66	0.21	0.37
2	WISC	0.29 ****	0.50	0.10	0.57
3 (n=40)	RT104	<0.01 $^{n.s.}$	-0.75	1.25	-0.07

Significant F change: * p<.05, ** p<.01, *** p<.001, **** p<.0001



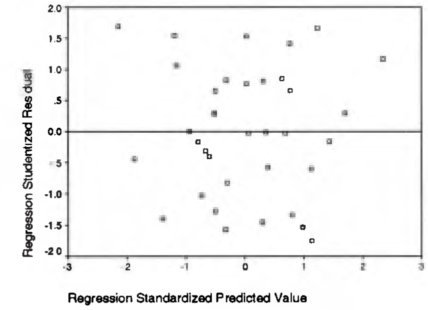
Dependent Variable: Number age
Predictor variables: Age, WISC and RT SSS4(negative probe)

Summary table of regression equation with Number age as the outcome measure, with age, non-verbal IQ and RT105 as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 2	0.29 ****	0.65	0.20	0.39
2	WISC	0.29 ****	0.39	0.11	0.44
3 (n=40)	RT105	0.03 $^{n.s.}$	-1.69	1.17	-0.19

Significant F change: * p<.05, ** p<.01, *** p<.001, **** p<.0001

Scatterplot



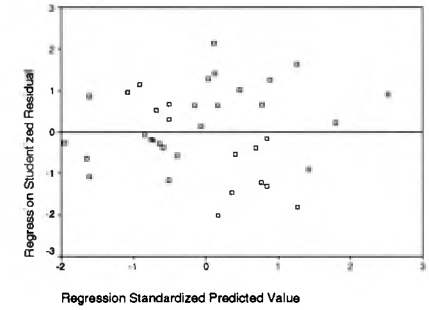
Dependent Variable: Number age
Predictor variables: Age, WISC and RT SSS5(negative probe)

Summary table of regression equation with Number age as the outcome measure, with age, non-verbal IQ and RT106 as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 2	0.29 ****	0.62	0.21	0.35
2	WISC	0.29 ****	0.49	0.10	0.57
3 (n=40)	RT106	0.01 $^{n.s.}$	-0.79	0.81	-0.11

Significant F change: * p<.05, ** p<.01, *** p<.001, **** p<.0001

Scatterplot



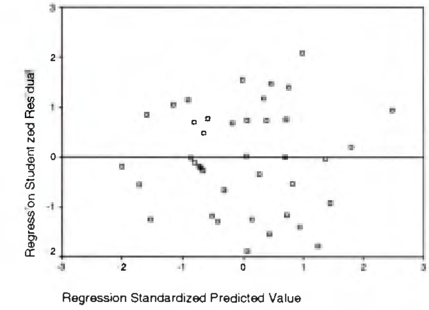
Dependent Variable: Number age
Predictor variables: Age, WISC and RT SSS6(negative probe)

Summary table of regression equation with Number age as the outcome measure, with age, non-verbal IQ and RT111 as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 2	0.29 ****	0.65	0.20	0.37
2	WISC	0.29 ****	0.48	0.10	0.55
3 (n=40)	RT111	<0.01 $^{n.s.}$	-0.40	1.21	-0.04

Significant F change: * p<.05, ** p<.01, *** p<.001, **** p<.0001

Scatterplot

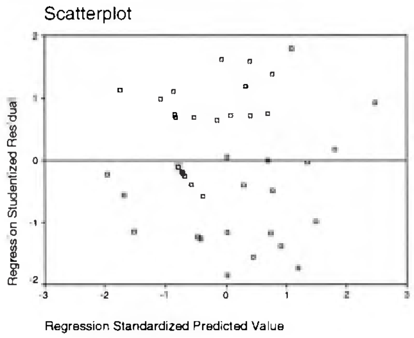


Dependent Variable: Number age
Predictor variables: Age, WISC and RT SSS1(positive probe)

Summary table of regression equation with Number age as the outcome measure, with age, non-verbal IQ and RT112 as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 2	0.29 ****	0.64	0.21	0.36
2	WISC	0.29 ****	0.48	0.10	0.55
3 (n=40)	RT112	<0.01 $^{n.s.}$	-0.51	0.91	-0.06

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$

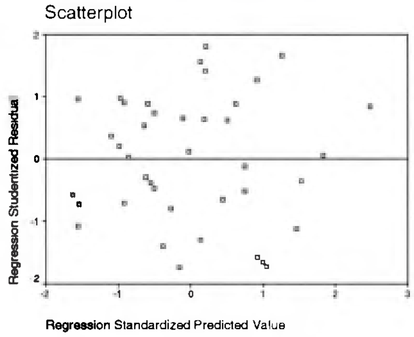


Dependent Variable: Number age
Predictor variables: Age, WISC and RT SSS2(positive probe)

Summary table of regression equation with Number age as the outcome measure, with age, non-verbal IQ and RT113 as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 2	0.29 ****	0.66	0.19	0.37
2	WISC	0.29 ****	0.44	0.09	0.50
3 (n=40)	RT113	0.06 *	-1.87	0.76	-0.25

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$

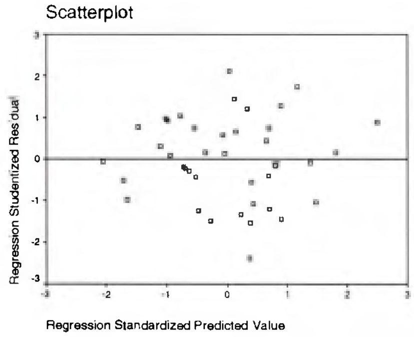


Dependent Variable: Number age
Predictor variables: Age, WISC and RT SSS3(positive probe)

Summary table of regression equation with Number age as the outcome measure, with age, non-verbal IQ and RT114 as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 2	0.29 ****	0.54	0.21	0.30
2	WISC	0.29 ****	0.49	0.10	0.56
3 (n=40)	RT114	0.03 $^{n.s.}$	-1.31	0.83	-0.18

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$

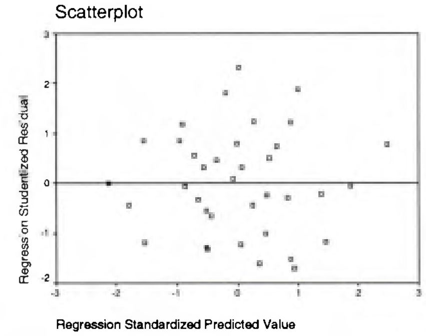


Dependent Variable: Number age
Predictor variables: Age, WISC and RT SSS4(positive probe)

Summary table of regression equation with Number age as the outcome measure, with age, non-verbal IQ and RT115 as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 2	0.29 ****	0.49	0.21	0.28
2	WISC	0.29 ****	0.51	0.10	0.60
3 (n=40)	RT115	0.02 $^{n.s.}$	-1.61	1.25	1.25

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$

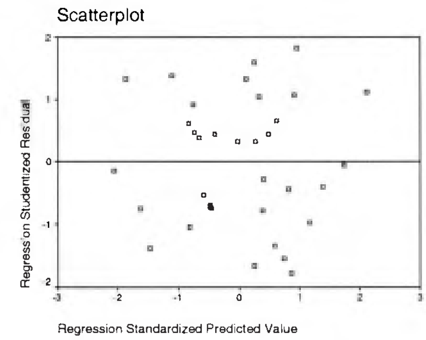


Dependent Variable: Number age
Predictor variables: Age, WISC and RT SSS5(positive probe)

Summary table of regression equation with Number age as the outcome measure, with age, non-verbal IQ and RT116 as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 2	0.29 ****	0.45	0.22	0.25
2	WISC	0.29 ****	0.48	0.10	0.57
3 (n=40)	RT116	0.03 $^{n.s.}$	-2.28	1.47	-0.20

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$

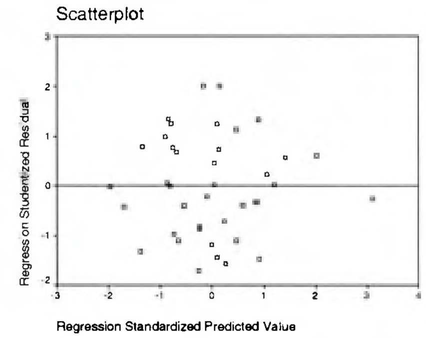


Dependent Variable: Number age
Predictor variables: Age, WISC and RT SSS6(positive probe)

Summary table of regression equation with Number age as the outcome measure, with age, non-verbal IQ and MIRA as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 2	.29 ****	0.37	.19	.21
2	WISC	.29 ****	0.42	.09	.48
3 (n = 40)	MIRA	.11 ***	1.72	.49	.39

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$



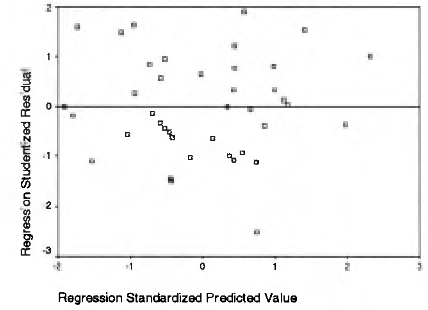
Dependent Variable: Number Age
Predictor variables: Age, WISC and MIRA

Summary table of regression equation with Number Age as the outcome measure, with age, non-verbal IQ and corrected P-HR as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 2	.29 ****	0.51	.16	.29
2	WISC	.29 ****	0.26	.10	.30
3 (n = 40)	Corrected P-HR	.15 ****	1.11	.25	.49

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$

Scatterplot



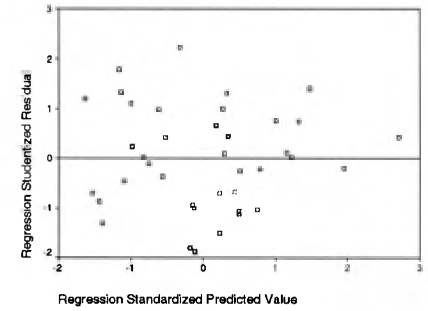
Dependent Variable: Number Age
Predictor variables: Age, WISC and Corrected P-HR

Summary table of regression equation with Number age as the outcome measure, with age, non-verbal IQ and corrected Change as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 2	.29 ****	0.53	.18	0.30
2	WISC	.29 ****	0.44	.09	0.50
3 (n = 40)	Corrected Change	.10 **	0.71	.21	0.33

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$

Scatterplot



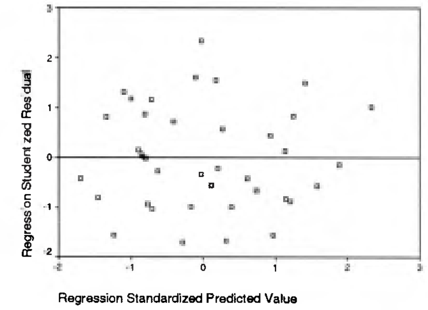
Dependent Variable: Number Age
Predictor variables: Age, WISC and Corrected Change

Summary table of regression equation with Number age as the outcome measure, with age, non-verbal IQ and Shop Task as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 2	0.29 ***	0.38	0.19	0.22
2	WISC	0.29 ****	0.35	0.09	0.40
3 (n = 40)	Shop task	0.12 ***	6.20	1.65	0.43

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$

Scatterplot

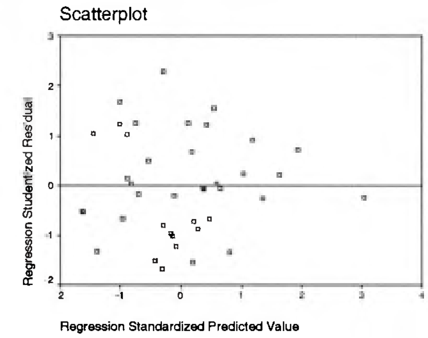


Dependent Variable: Number Age
Predictor variables: Age, WISC and Shop Task

Summary table of regression equation with Number Age as the outcome measure, with age, non-verbal IQ, MIRA and corrected Change as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 2	0.29 ***	0.39	0.19	0.22
2	WISC	0.29 ***	0.41	0.09	0.47
3	MIRA	0.11 ***	1.17	0.57	0.26
4 (n = 40)	Corrected Change	0.03 $^{n.s.}$	0.25	0.25	0.20

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$

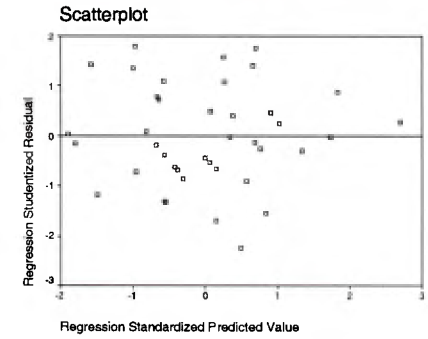


Dependent Variable: Number Age
Predictor variables: Age, WISC, MIRA and corrected Change

Summary table of regression equation with Number Age as the outcome measure, with age, non-verbal IQ, MIRA and corrected P-HR as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 2	0.29 ****	0.38	0.17	0.22
2	WISC	0.29 ****	0.27	0.09	0.31
3	MIRA	0.11 ****	0.96	0.50	0.22
4 (n =40)	corrected P-HR	0.07 **	0.86	0.28	0.38

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$

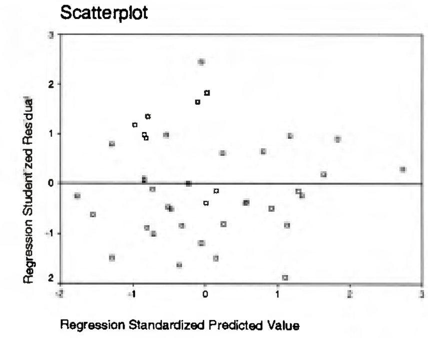


Dependent Variable: Number Age
Predictor variables: Age, WISC, MIRA and corrected P-HR

Summary table of regression equation with Number Age as the outcome measure, with age, non-verbal IQ, MIRA and Shop Task as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 2	0.29 ****	0.31	0.19	0.18
2	WISC	0.29 ****	0.36	0.09	0.41
3	MIRA	0.11 ***	1.00	0.59	0.22
4 (n = 40)	Shop Task	0.03 *	4.12	2.02	0.29

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$

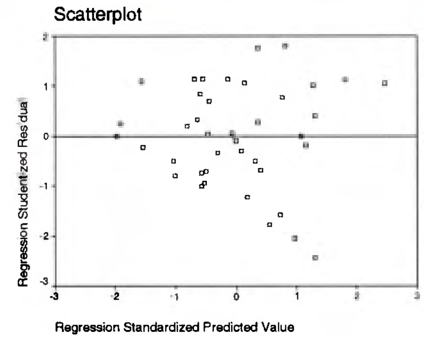


Dependent Variable: Number Age
Predictor variables: Age, WISC, MIRA and Shop Task

Summary table of regression equation with NFER (3) as the outcome measure, with age, non-verbal IQ and memory as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 3	0.24 ***	0.003	0.001	0.34
2	WISC	0.16 **	0.002	0.001	0.38
3 (n = 40)	Memory	<0.01 $^{n.s.}$	0.004	0.006	0.10

Significant F change: * *p*<.05, ** *p*<.01, *** *p*<.001, **** *p*<.0001

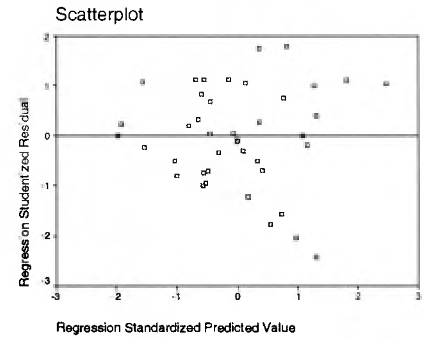


Dependent Variable: NFER3
Predictor variables: Age, WISC and Memory

Summary table of regression equation NFER(3) age as the outcome measure, with age, non-verbal IQ and RT101as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 3	0.24 ***	0.003	0.001	0.35
2	WISC	0.16 **	0.002	0.001	0.40
3 (n=40)	RT101	0.06 $^{n.s.}$	-0.008	0.004	-0.25

Significant F change: * *p*<.05, ** *p*<.01, *** *p*<.001, **** *p*<.0001

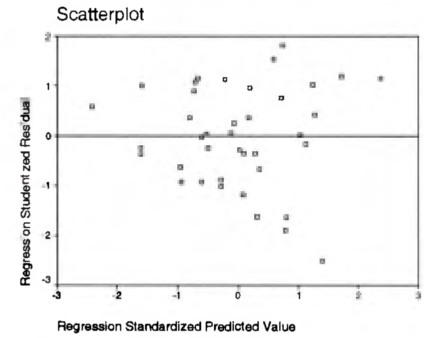


Dependent Variable: NFER(3)
Predictor variables: Age, WISC and RT SSS1(negative probe)

Summary table of regression equation with NFER(3) as the outcome measure, with age, non-verbal IQ and RT102 as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 3	0.24 ***	0.003	0.001	0.33
2	WISC	0.16 **	0.002	0.001	0.34
3 (n=40)	RT102	0.02 $^{n.s.}$	-0.003	0.003	-0.51

Significant F change: * *p*<.05, ** *p*<.01, *** *p*<.001, **** *p*<.0001

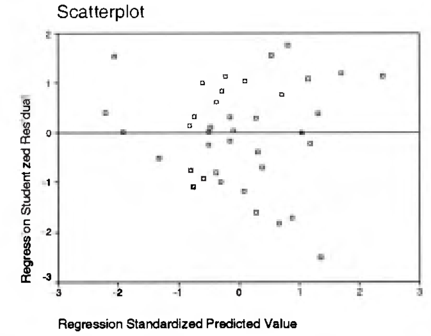


Dependent Variable: NFER(3)
Predictor variables: Age, WISC and RT SSS2(negative probe)

Summary table of regression equation with NFER(3) as the outcome measure, with age, non-verbal IQ and RT103 as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 3	0.24 ***	0.003	0.001	0.34
2	WISC	0.16 **	0.002	0.001	0.33
3 (n=40)	RT103	0.03 $^{n.s.}$	-0.005	0.005	-0.17

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$

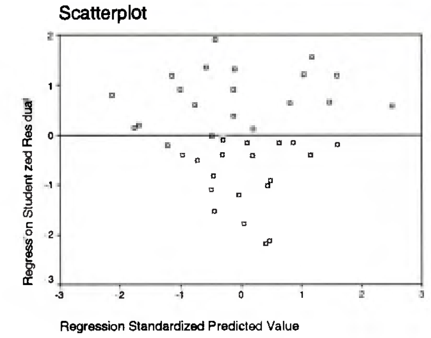


Dependent Variable: NFER(3)
Predictor variables: Age, WISC and RT SSS3(negative probe)

Summary table of regression equation with NFER(3) as the outcome measure, with age, non-verbal IQ and RT104 as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 3	0.24 ***	0.002	0.001	0.23
2	WISC	0.16 **	0.002	0.0001	0.40
3 (n=40)	RT104	0.23 ****	-0.03	0.006	-0.49

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$

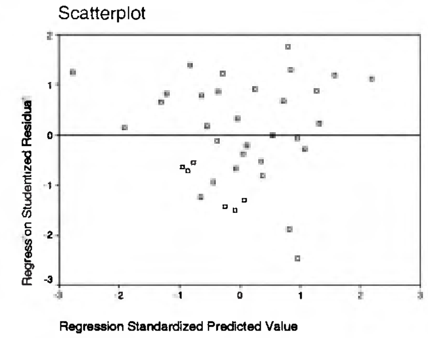


Dependent Variable: NFER(3)
Predictor variables: Age, WISC and RT SSS4(negative probe)

Summary table of regression equation with NFER(3) as the outcome measure, with age, non-verbal IQ and RT105 as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 3	0.24 ***	0.003	0.001	0.32
2	WISC	0.16 **	0.001	0.001	0.29
3 (n=40)	RT105	0.06 $^{n.s.}$	-0.01	0.007	-0.29

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$

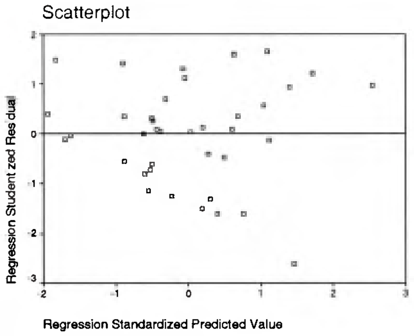


Dependent Variable: NFER(3)
Predictor variables: Age, WISC and RT SSS5(negative probe)

Summary table of regression equation with NFER(3) as the outcome measure, with age, non-verbal IQ and RT106 as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 3	0.24 ***	0.002	0.001	0.27
2	WISC	0.16 **	0.002	0.001	0.46
3 (n=40)	RT106	0.05 $^{\text{n.s.}}$	-0.008	0.005	-0.23

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$

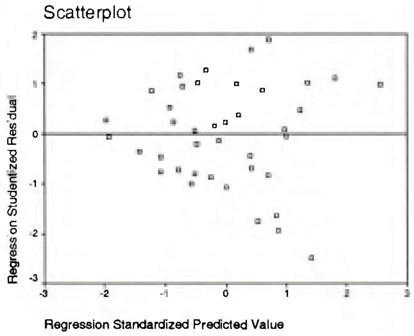


Dependent Variable: NFER(3)
Predictor variables: Age, WISC and RT SSS6(negative probe)

Summary table of regression equation with NFER(3) as the outcome measure, with age, non-verbal IQ and RT111 as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 3	0.24 ***	0.003	0.001	0.37
2	WISC	0.16 **	0.002	0.001	0.43
3 (n=40)	RT111	<0.01 $^{\text{n.s.}}$	0.002	0.007	0.04

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$

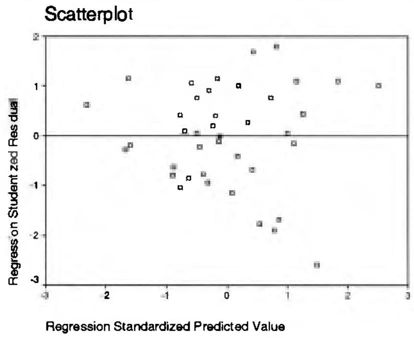


Dependent Variable: NFER(3)
Predictor variables: Age, WISC and RT SSS1(positive probe)

Summary table of regression equation with NFER(3) as the outcome measure, with age, non-verbal IQ and RT112 as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 3	0.24 ***	0.003	0.001	0.33
2	WISC	0.16 **	0.002	0.001	0.40
3 (n=40)	RT112	0.01 $^{\text{n.s.}}$	-0.004	0.006	-0.11

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$

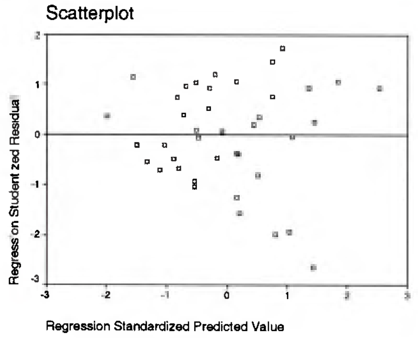


Dependent Variable: NFER(3)
Predictor variables: Age, WISC and RT SSS2(positive probe)

Summary table of regression equation with NFER(3) as the outcome measure, with age, non-verbal IQ and RT113 as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 3	0.24 ***	0.003	0.001	0.37
2	WISC	0.16 **	0.002	0.001	0.36
3 (n=40)	RT113	0.04 $^{n.s.}$	-0.008	0.005	-0.21

Significant F change. * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$

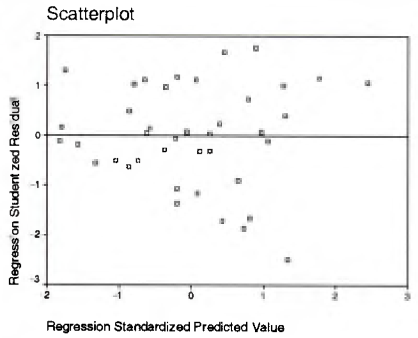


Dependent Variable: NFER(3)
Predictor variables: Age, WISC and RT SSS3(positive probe)

Summary table of regression equation with NFER(3) as the outcome measure, with age, non-verbal IQ and RT114 as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 3	0.24 ***	0.002	0.001	0.29
2	WISC	0.16 **	0.002	0.001	0.39
3 (n=40)	RT114	0.04 $^{n.s.}$	-0.007	0.006	-0.17

Significant F change. * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$

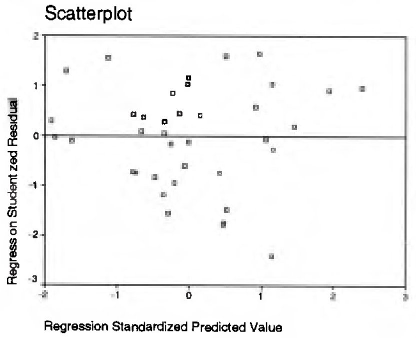


Dependent Variable: NFER(3)
Predictor variables: Age, WISC and RT SSS4(positive probe)

Summary table of regression equation with NFER(3) as the outcome measure, with age, non-verbal IQ and RT115 as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 3	0.24 ***	0.002	0.001	0.29
2	WISC	0.16 **	0.002	0.001	0.37
3 (n=40)	RT115	0.04 $^{n.s.}$	-0.01	0.008	-0.23

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$



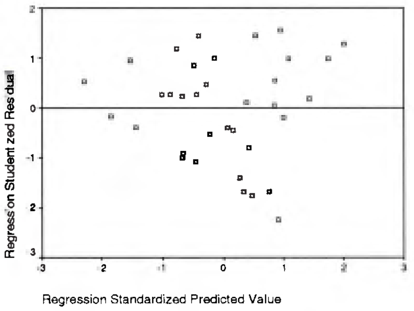
Dependent Variable: NFER(3)
Predictor variables: Age, WISC and RT SSS5(positive probe)

Summary table of regression equation with NFER (3) as the outcome measure, with age, non-verbal IQ and RT116 as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 3	0.24 ***	0.002	0.001	0.25
2	WISC	0.16 **	0.002	0.001	0.36
3 (n=40)	RT116	0.03 $^{n.s.}$	-0.01	0.01	-0.21

Significant F change: * *p*<.05, ** *p*<.01, *** *p*<.001, **** *p*<.0001

Scatterplot



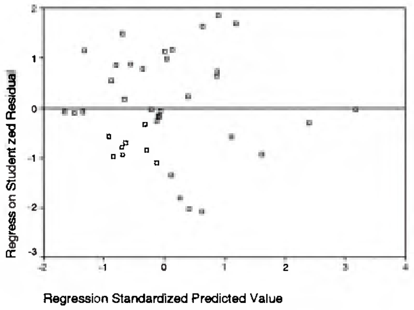
Dependent Variable: NFER 3
Predictor variables: Age, WISC and RT SSS6(positive probe)

Summary table of regression equation with NFER (3) as the outcome measure, with age, non-verbal IQ and MIRA as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 3	0.24 ***	0.001	0.001	0.17
2	WISC	0.16 **	0.001	0.001	0.28
3 (n = 40)	MIRA	0.15 **	0.01	0.003	0.47

Significant F change: * *p*<.05, ** *p*<.01, *** *p*<.001, **** *p*<.0001

Scatterplot



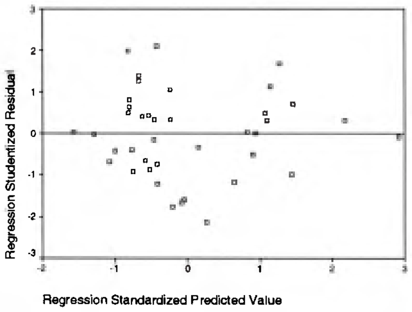
Dependent Variable: NFER3
Predictor variables: Age, WISC and MIRA

Summary table of regression equation with NFER (3) as the outcome measure, with age, non-verbal IQ and CELF-OD as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 3	0.24 ***	0.002	0.001	0.26
2	WISC	0.16 **	0.001	0.001	0.18
3 (n = 40)	CELF-OD	0.26 ****	0.009	0.002	0.54

Significant F change: * *p*<.05, ** *p*<.01, *** *p*<.001, **** *p*<.0001

Scatterplot

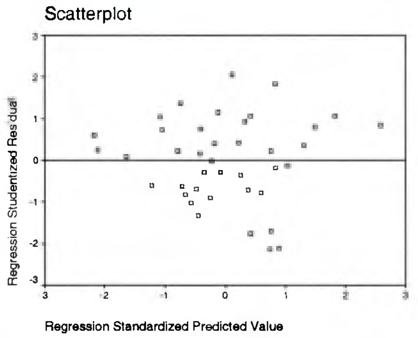


Dependent Variable: NFER3
Predictor variables: Age, WISC and CELF-OD

Summary table of regression equation with NFER (3) as the outcome measure, with age, non-verbal IQ and CELF-SS as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 3	0.24 ***	0.002	0.001	0.27
2	WISC	0.16 **	0.001	0.001	0.33
3 (n = 40)	CELF-SS	0.06 *	0.005	0.002	0.29

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$

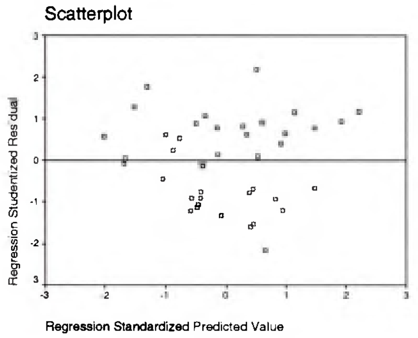


Dependent Variable: NFER3
Predictor variables: Age, WISC and CELF-SS

Summary table of regression equation with NFER (3) as the outcome measure, with age, non-verbal IQ and corrected P-HR as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 3	0.24 ***	0.002	0.001	0.27
2	WISC	0.16 **	0.001	0.001	0.16
3 (n = 40)	Corrected P-HR	0.11 **	0.005	0.002	0.44

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$

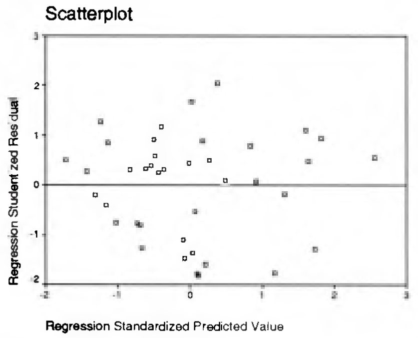


Dependent Variable: NFER3
Predictor variables: Age, WISC and Corrected P-HR

Summary table of regression equation with NFER (3) as the outcome measure, with age, non-verbal IQ and Corrected Change as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 3	0.24 ***	0.002	0.001	0.22
2	WISC	0.16 **	0.001	0.001	0.29
3 (n = 40)	Corrected Change	0.22 ****	0.01	0.001	0.51

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$

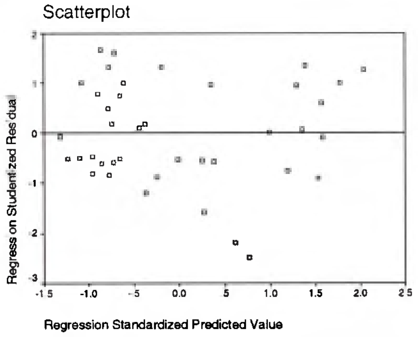


Dependent Variable: NFER3
Predictor variables: Age, WISC and Corrected Change

Summary table of regression equation with NFER (3) as the outcome measure, with age, non-verbal IQ and Shop Task as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 3	0.24 **	0.001	0.001	0.17
2	WISC	0.16 **	0.001	0.001	0.18
3 (n = 40)	Shop Task	0.18 ****	0.04	0.01	0.55

Significant F change. * *p*<.05, ** *p*<.01, *** *p*<.001, **** *p*<.0001

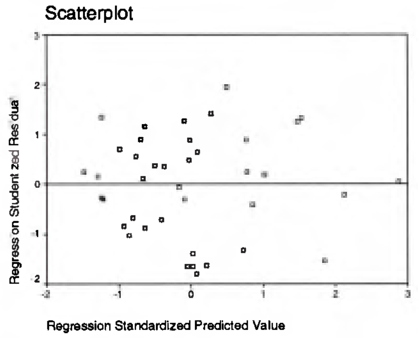

Scatterplot

Dependent Variable: NFER3
Predictor variables: Age, WISC and Shop Task

Summary table of regression equation with NFER (3) as the outcome measure, with age, non-verbal IQ, MIRA and corrected Change as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 3	0.24 ***	0.001	0.001	0.15
2	WISC	0.16 **	0.001	0.001	0.24
3	MIRA	0.15 **	0.006	0.003	0.27
4 (n =40)	Corrected Change	0.09 **	0.008	0.003	0.38

Significant F change: * *p*<.05, ** *p*<.01, *** *p*<.001, **** *p*<.0001

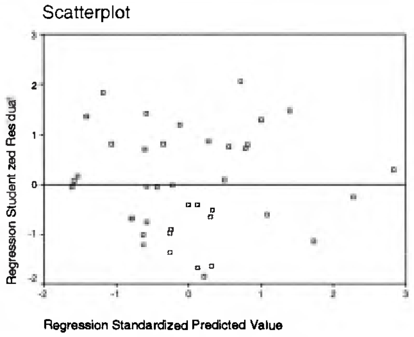

Scatterplot

Dependent Variable: NFER3
Predictor variables: Age, WISC, MIRA and corrected Change

Summary table of regression equation with NFER (3) as the outcome measure, with age, non-verbal IQ, MIRA and corrected P-HR as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 3	0.24 ***	0.001	0.001	0.15
2	WISC	0.16 **	0.001	0.001	0.15
3	MIRA	0.15 **	0.008	0.003	0.37
4 (n = 40)	Corrected P-HR	0.04 $^{n.s.}$	0.003	0.002	0.28

Significant F change: * *p*<.05, ** *p*<.01, *** *p*<.001, **** *p*<.0001

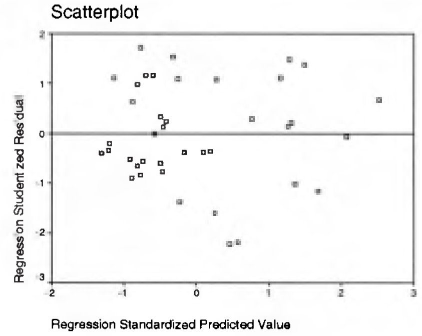

Scatterplot

Dependent Variable: NFER3
Predictor variables: Age, WISC, MIRA and corrected P-HR

Summary table of regression equation with NFER (3) as the outcome measure, with age, non-verbal IQ, MIRA and Shop Task as the explanatory variables.

Step	Variable	R^2 Change	B	SE B	β
1	Age at time 3	0.24 ***	0.001	0.001	0.12
2	WISC	0.16 **	0.001	0.001	0.17
3	MIRA	0.15 **	0.001	0.004	0.25
4 (n = 40)	Shop Task	0.06 *	0.03	0.01	0.40

Significant F change: * $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$



Dependent Variable: NFER3
Predictor variables: Age, WISC, MIRA and Shop Task