How Learning New Words Changes Lexical Networks During Developmental Language Acquisition

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I, Diane Hiu Wai Leung confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

ABSTRACT

The thesis uses connectionist ideas as a basis for understanding lexical processing, in particular how usage factors have an effect on lexical production in early development. The usage factors of word frequency, neighbourhood density and age-of-acquisition are considered and manipulated in word and non-word repetition tasks with children aged 2 to 12 years. First-order neighbourhood density refers to adjacent neighbours of a target word and second-order neighbourhood density refers to neighbours of first-order neighbours. First- and second-order neighbourhood changes over age were calculated. Experiments were conducted to see how these and the other usage factors interact. A particular focus was whether a phone string is processed differently depending on whether it is a word a child knows or is effectively a non-word (i.e. a word not acquired until a later age). A Generative Acquisition Hypothesis Processing Shift Model is proposed explaining how a string of phones that is a non-word (not known by a child of this age) is processed differently to when it is acquired and how this leads to different interactions between usage factors on lexical processing. The thesis then extends this model by investigating usage factors in Cantonese-English bilinguals as well as Cantonese monolinguals. The results provide a better understanding about how the lexicon develops over ages and how the links between words changes (using the neighbourhood density statistics) within children of different ages and between two languages in bilingual children.

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1 Chapter 1: Overview

1.1 Background

The primary goal of this PhD was to conduct research that would enhance the understanding of lexical development in early childhood. The factors investigated were those concerned with lexical usage (word frequency, neighbourhood density, age-of-acquisition, and word/non-word status). The way these interacted with one another was explored in relation to children's word production.

A particular focus was to extend current research by exploring the effects of remote neighbours. In most studies, properties of close phonological neighbours to a word have been investigated. For example, 'cat' has 'cut' as an adjacent or first-order neighbour because changing the vowel changes the word from the target word to the neighbouring word. In this PhD, second-order neighbourhood effects (word neighbours of first-order [adjacent] neighbours) were investigated, something which has not been done previously.

In order to understand the changes that occur in neighbourhood density statistics over development in childhood, two computational studies were performed. These allowed materials to be developed for the three behavioural experiments on children that were conducted. Unlike existing neighbourhood density calculators, the computational work performed in this thesis took into account age at which words were acquired (word age-of –acquisition) and the effects this has on first- and second-neighbourhood density.

The motivation for this work stemmed from connectionist approaches to language. The Interactive Activation Model (McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982), that is a connectionist approach, is evaluated in Chapter 2. It was chosen as the most promising model for understanding how children's lexicons develop. Connectionist models have a biological basis that enables them to specify how multiple factors interact and affect word processing. The links between words in the lexicon allow massive connectivity between words within the lexicon.

The Interactive Activation Model has been useful in interpreting the inconsistent findings across studies regarding the effects of neighbourhood density on word processing (Arduino & Burani, 2004; Garlock, Walley, & Metsala, 2001; Luce & Pisoni, 1998; Metsala, 1997a). Some studies report a facilitatory effect on word processing that can be explained by the assumption that activation in words that share the same phonemes sum together (Grainger & Jacobs, 1996). Other studies that report an inhibitory effect (e.g. McClelland & Rumelhart, 1981) can be explained by the assumption that lateral inhibition between items (competition between neighbouring words) occurs.

It is important to note that word age-of-acquisition data have not been considered in many studies when neighbourhood density statistics have been calculated. This potentially makes the results obtained in neighbourhood density experiments invalid for children. As a child develops, new words are acquired (changing a string of phones from a non-word to a word in the lexicon). This then affects the word neighbourhood densities of all words the child knows. Therefore, it is important to consider what words have currently been acquired by a child before calculating neighbourhood density statistics, as the former affects the latter.

Furthermore, the concept of the change from a non-word to a word in the lexicon is crucial. This is because models have been proposed which hypothesise differences in lexical versus sublexical processing where the form of processing depends on whether a string of phones is treated as a word or non-word (Vitevitch & Luce, 1998). This idea about how a non-word becomes a word is important in early language development, a period in which a significant amount of word acquisition happens (Ganger & Brent, 2004; Goldfield & Reznick, 1990; Mayor & Plunkett, 2010). This process is also encountered in second language acquisition, as a bilingual speaker has to acquire a large number of words into the lexicon of their second language. Studies in the bilingualism literature have shown there are different neighbourhood density effects on word processing in monolinguals and bilinguals. These findings indicate that the presence of a second language can affect the way the first language is processed (Jared & Kroll, 2001; Van Heuven, Dijkstra, & Grainger, 1998).

It is recognised that existing methodologies for calculating neighbourhood density statistics need to be suitable for assessing children (Garlock et al., 2001; Metsala, 1997a, 1997b; Storkel & Hoover, 2010). The current computational studies took into account word age-of-acquisition data using the CHILDES database in order to obtain precise statistics of words known at particular ages. With the improved methodology and neighbourhood density statistics obtained with the latter, material was selected for experiments, which investigated the effects of neighbourhood density on monolingual and bilingual children's word production.

1.2 Overview of Thesis

A literature review in Chapter 2 presents the ideas and models from the connectionists' approach, exploring the current problems with studies in word neighbourhood statistics, before considering other models that explain the effects that neighbourhood density has on word production. Here a Generative Acquisition Hypothesis Processing Shift Model, developed from Vitevitch and Luce's (1998) prior work, was proposed to explain word and non-word neighbourhood density effects on lexical processing. This model was used as the basis of the hypotheses in the experimental studies.

Chapter 3 implements an improved methodology for neighbourhood density calculations. A computational analysis was performed on data from CHILDES so that neighbourhood statistics at developmental stages could be computed. In particular, data on the way the number of words with high and low density of word neighbours changes as age increases was obtained.

Using the results from the computational analysis, materials were designed to test the influence of high and low first- and second-neighbourhood density words on children's word production speed in a picture-naming task. This was conducted on 27 pre-school children (reported in Chapter 4). Due to a number of methodological issues with this experiment, the results were inconclusive. Further computational analyses were conducted in Chapter 5. This solved some of the limitations of Chapter 4 by extending neighbourhood density calculations to multisyllabic words and to both words and pseudo-words (pseudo-words are non-words which would follow English phonotactic constraints but would never be acquired by a child). These calculations were made on words known at ages 3 and 5. The materials obtained from Chapter 5 were used as stimuli in a repetition task in Chapter 6 with children in two age groups (under 5 and over 5) to determine if processing is affected by whether a string of phones is currently treated as a word or not (as predicted by the Generative Acquisition Hypothesis Processing Shift Model).

For the children in the younger age group, words known after age 5 would be words not yet known (phone strings that are not currently words in a child's lexicon, but will become words when they are learned at later ages). By testing the two age groups it is possible to see whether there are processing differences as phone string change their word-non-word status. The experiment was only partly successful as predicted interactions between age and phone string group comparison for the first- and second-order neighbourhood density groups were absent for words and pseudo-words. However, there were main effects of age across all comparison, except for when phone string groups were compared within words known at age 3. The age group effect indicates that there may be a shift in processing from the sublexical to lexical level when a phone string is established in the lexicon as a word.

Chapter 7 presents the results from a further study based on the findings from Chapter 6. In Chapter 7, the same test material and procedure was used with Cantonese-English bilinguals and Cantonese monolinguals to see whether lexical development was affected by language background. Data from a language history questionnaire was collected. The results demonstrated that there were effects of language background across all phone string categories, as there was a main effect of language group. This indicated that, overall, the bilinguals were disadvantaged in their lexical processing. However, when looking at the interactions between language background and neighbourhood density, the disadvantage in processing for the bilinguals only occurred in the pseudo-word set. Finally, Chapter 8 draws on the findings from the work reported and uses connectionist views to specify how lexical usage factors should be incorporated into models of child language.

2 Chapter 2: Introduction and Review of the Literature

2.1 Introduction

This literature review assesses existing theories and models of language from the connectionist's approach that account for word retrieval in word recognition and production. These ideas are used as a framework to investigate how the lexicon develops at a young age. The first part of the literature review describes the main connectionist model for language and considers how well it explains lexical processing in word recognition and production. The way word usage factors can be included in this connectionist model are discussed. A specific focus is how the word usage factor of word neighbourhood density could operate in this model. The second part of the literature review considers how the connectionist model could apply to aspects of early language development, in particular how words are acquired and represented in the mental lexicon. The latter topic is approached in terms of how a phone string that is a non-word prior to its acquisition at a particular age changes at later ages and becomes a word in the child's lexicon.

2.2 The Connectionist Approach to Language

In the past, psychologists mainly approached language processing as a step by step process, where words were regarded as having separate representations that do not interact with other words (Indurkhya & Damerau, 2010). More recently, the connectionist approach to language has been favoured over such classical approaches to language processing.

The connectionist approach in general uses principles from neurobiology and human cognition as its basis. Connectionist models of language processing use these same principles and are able to address critical problems psychologists have raised. For example, as connectionist models take an interactive, parallel approach to language processing, they can help explain the rapidity of cognitive language processing, which is something that modular, serial classical models cannot do (Christiansen & Chater, 2001; Fodor & Pylyshyn, 1988).

In the connectionist approach, emphasis is placed on hypothesised networks of neurons in the brain. In these networks, each individual neuron acts as a node that contains a unit of information about a word, such as whether or not a particular phone is present. When these nodes connect and pass on information to each other through action potentials between neurons (either excitatory or inhibitory), the details about a word can be retrieved and used in recognition and production (Clark, 2005; Nunez, n.d.). The level of activation for each receiving neuron (another node in the network) can vary. The connectionist approach considers that the weights of the nodes change during learning as the networks adapt to new input, such as new words entering the lexicon (Elman, 1998; Plaut, 2003).

Nodes can be mapped together in many ways. Some important ones used in language models are one-to-one, many-to-one, one-to-many and many-to-many mappings (Berntson & Cacioppo, 2009). These mappings allow, respectively, nodes to be activated by one other single node, or by a group of other nodes, for one node to activate several other nodes at the same time or for one group of nodes to activate another group of nodes. The types of possible mappings of nodes in the lexicon are important as they can be used to explain how multiple usage factors can have an effect on single word processing. For example, they can explain how nodes that contain information about a word such as its word frequency and neighbourhood density connect with one another to influence processing. Based on these ideas, connectionist models in language are complex because there are a large number of words in the lexicon of speakers who have language competency. This results, therefore, in a large number of connections between word nodes in the lexicon (referred to as massive connectivity).

Complete models of language that use the concept of neural networks have to consider phonology, morphology, syntax and semantics as factors (Plaut, 2003). As a result of this, researchers have sought to represent lexical networks by constructing models that connect words to model influences of different lexical factors (Chan & Vitevitch, 2010; Collins & Loftus, 1975; Levelt, 1999; Roelofs, 1992). In this thesis, a specific focus is on how the connectionist approach applies to phonology.

2.2.1 *Applying the Connectionist Approach to Phonological Networks*

This thesis focuses on phonological factors in language acquisition and early language development. The reason for considering phonological factors in early lexical development is because this is the period when phonological processing develops, as a child is exposed to language input. Many studies have shown how infants learn sounds and begin to perceive them categorically at a young age (Eimas, 1975; Jusczyk, Rosner, Cutting, Foard, & Smith, 1977). Studies have shown that infants are able to focus on their native language and contrast vowels at 6 months of age (Kuhl, Williams, Lacerda, Stevens, & Lindblom, 1992) and consonants at 10 to 12 months of age (Werker & Tees, 1984). In contrast, semantics is only observed from 12 to 18 months of age (Brandone, Salkind, Golinkoff, & Hirsh-Pasek, 2006; Thomas, Campos, Shucard, Ramsay, & Shucard, 1981; Werker, Cohen, Lloyd, Casasola, & Stager, 1998). Phonology is, therefore, an important initial step in language acquisition that happens before semantics come into play (Kuhl, 2004).

Phonology can be understood as a general learning process whereby the statistical properties of the sound elements in the words heard are learned according to general principles (word usage). In the case of understanding child language development, the usage point of view helps to explain how phonological networks develop and change over the period of language acquisition.

One of the lexical factors that links in with phonological networks and is of particular interest in this thesis is the influence of word neighbourhood density. Landauer and Streeter (1973) defined the statistical concept of neighbourhood density (also known as phonological neighbourhood density), as the number of word neighbours a target word has. The number of word neighbours is obtained by substituting, deleting or adding a single phoneme to the target word. As an example, the word 'cat' has the neighbour 'hat' through phoneme substitution, 'at' through phoneme deletion and 'catch' through phoneme addition. Single phoneme substitution, deletion or addition can happen in three different locations in the syllables within a word: 1) on the initial consonant or cluster of consonants at the start of a syllable (onset); 2) on the vowel in a syllable; or 3) on the final consonant or consonant cluster in a syllable (coda) (De Cara & Goswami, 2002). By making these manipulations on word cohorts, neighbourhood density calculators can determine the number of word neighbours a target word has. A number of these calculators are available online for both words and non-words (De Cara & Goswami, 2002; Rastle, Harrington, & Coltheart, 2002; Storkel & Hoover, 2010).

Words vary in the number of neighbours that they have. Those with a high number of neighbours would have a larger number of connections to other words whereas those with a low number of neighbours would have fewer connections (Vitevitch, 2008). Research in the area has shown that there may be a benefit in language processing when networks are small (low neighbourhood densities) compared to when they are large (high neighbourhood densities) (Arnold, Conture, & Ohde, 2005; Garlock et al., 2001; Luce & Pisoni, 1998; Vitevitch, Luce, Pisoni, & Auer, 1999; Vitevitch & Luce, 1998; Ziegler, Muneaux, & Grainger, 2003). With smaller networks, fewer words are available, so there is less competition and word selection is easy (Chan & Vitevitch, 2010). These ideas are supported and can be simulated in connectionist models of language, as the connectionists' approach proposes that words in the lexicon are all connected with one another so they influence the way each other are processed. In the following section, the main connectionist model of language is discussed to help understand the effects of word neighbourhood density on lexical processing.

2.3 Models of Language Processing

Models of language processing are used to try to explain how words are recognised and processed by individuals. Some models consider that when a word is presented in either spoken or written form it is necessary that its features are identified so that the relevant access points or nodes in the lexicon can be found and thus the required outputs can be initiated. For example, when the word ‘cat’ is presented, an individual has to access information about this word in the mental lexicon. By identifying some of its features, such as the phonemes that comprise it, its word frequency and its semantic representation to name a few, the word can be correctly retrieved and a relevant output such as producing the word ‘cat’ can be initiated. Many word usage factors can therefore affect word processing. In this thesis the features of word frequency (how frequent a word appears in speech), word neighbourhood density (the number of word neighbours through phoneme substitution, deletion or addition) and word/non-word processing (whether a string of phones is known to be a word or not known and treated as a non-word by an individual) are considered.

As previously discussed, word neighbourhood density is one of the usage factors that is focused on due to its importance in understanding phonological networks. Word frequency is often also discussed in models along with word neighbourhood density as studies in the literature have looked at the way the two factors interact (Goldinger, Luce, & Pisoni, 1989; Metsala, 1997a; Munson & Solomon, 2004; Siakaluk, Sears, & Lupker, 2002). In addition to these factors, word-non-word processing is considered because it provides insight into how words that are not known by an individual child at one age (non-word) are acquired into the lexicon through development. When a child learns his/her first language, phone strings presented are only treated as phonological information (non-words). Each string requires integration into the lexicon by linking form with meaning before it can be considered to be acquired and to become a word (Gaskell & Dumay, 2003; Li, Zhao, & Mac Whinney, 2007). As the way words and non-words are processed differ, it is important to consider how language processing models account for these processing differences and what changes to this process happen once a word has been learned. The way the connectionist approach explains such processing is considered next building up from early models to contemporary ones that incorporate usage factors.

2.3.1 *Interactive Activation Model*

The Interactive Activation Model (McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982) was an early connectionist model of lexical processing whereby words in the lexicon are considered to be connected to one another instead of being independent entities, in a similar way to how neurons are connected and send signals to each other (Figure 2-1). In this model, each word is represented as a node (unit of information). The connections between nodes can be mapped in many ways as described earlier (Berntson & Cacioppo, 2009). This model assumes that there are also letter level nodes and feature level nodes (or detectors) which connect with each other and words (Figure 2-1). Instead of storing all the information about a word, letter level and feature level nodes only represent the letters or phonemes of a word and visual features of the letters of a word respectively. Each word node has specific letter and feature nodes that connect to form the word.

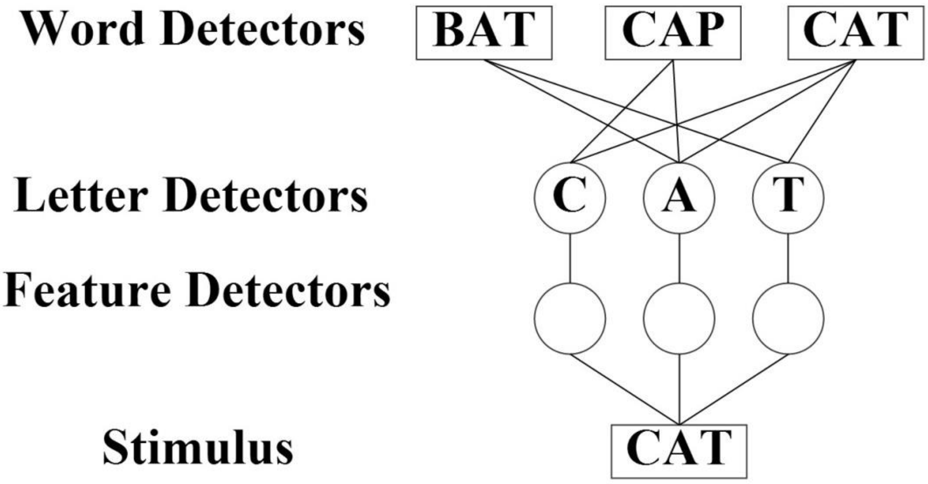

Figure 2-1. Diagram illustrating how words are processed in the Interactive Activation Model (McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982). Lines represent excitatory connections between nodes (detectors).

When a stimulus such as the word 'cat' is presented (Figure 2-1), signals are first sent to the feature level nodes so that those that correspond can be activated. In the case of visual stimuli, the feature level nodes react to the features of the letters presented, such as their shape and the direction of the strokes. Whereas in the case of speech perception, the phoneme sequence presented is converted so that each individual phoneme unit can be identified (based on the TRACE model adaptation of the Interactive Activation Model of (McClelland & Elman, 1986)). The feature detectors help to determine which letters or phonemes are present in the stimulus, so that the corresponding letter level nodes can be activated. Signals are therefore passed on from the stimulus to the feature detectors and then to the letter detectors.

Once the signals reach the letter detectors, the letter level nodes can either excite or inhibit the relevant word-level nodes depending on the letter's position in the stimulus. For example, in the word 'cat', the letter 'c' will excite the word level nodes of ‘cap’ and ‘cat’ but would inhibit the word level node of ‘bat’ (Figure 2-1). Similarly the word-level nodes feed back and inhibit all the lower level letter nodes that are not relevant by only activating those that match, so the word node ‘cat’ would only activate the letter detectors of ‘c’, ‘a’ and ‘t’. The Interactive Activation Model therefore operates in a bottom-up and top-down fashion where the stimulus drives processing up from the bottom (bottom-up) and the expectation of what the word should be drives processing down from the top (top-down). This bottom-up and top-down interactive approach helps to ensure that the target word is correctly recognised and the appropriate output can be initialised.

The Interactive Activation Model accounts for word frequency effects by proposing that words with high frequencies are activated faster than words with low frequency. This is because high frequency words are assumed to have a higher base rate activation level (McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982). This means that high frequency words start off with a higher activation level than low frequency words, so they require little further activation to reach their threshold. Consequently, high frequency words are responded to quickly.

The model becomes more complicated when dealing with non-words as the reaction time to a non-word depends on the position of the letters in the non-word and its number of word neighbours in the lexicon (word neighbourhood density). The reason for this is that a non-word could be mistaken for a word in the lexicon when it has similar letter nodes to real words, thus a non-word that follows the phonotactic constraints of a language will take longer to respond to than a non-word that does not follow phonotactic restrictions.

A non-word that follows phonotactic restrictions activates letter level nodes that have more relevant word level nodes than a non-word that does not follow phonotactic restrictions (McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982). For example, the non-word ‘rop’ that follows phonotactic restrictions can activate word level nodes such as ‘hop’, ‘rob’ and ‘rip’, as they have similar letter level nodes. Thus, an individual would have to reassess the input (double checking the response by using both bottom-up and top-down processing) before they are able to determine whether the target phone string is a word or non-word (Figure 2-2). Conversely, non-words that have no word neighbours have no closely related word level nodes in the lexicon and the recognition that the target presented is a non-word would be faster.

Consequently, the neighbourhood densities of words play a significant role in non-word processing. Non-words with high neighbourhood densities would activate all of their neighbours when they are presented as a stimulus, thus these non-words would seem more familiar and less like a non-word than a non-word with few neighbours (Cottrell, 1996). These ideas therefore have implications for lexical development, as the more words that are acquired into the lexicon, the word neighbourhood density of a non-word will also change. Thus non-word processing will be affected by the number of words an individual knows, which is often determined by age.

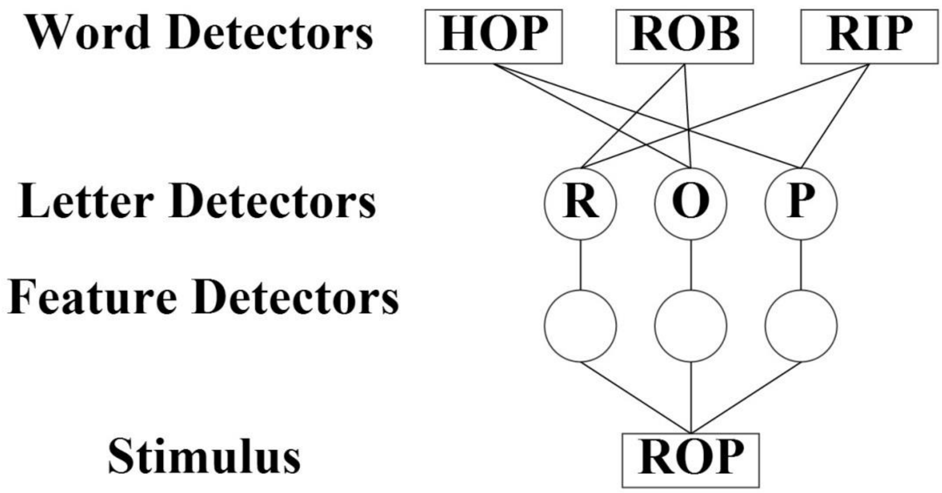

Figure 2-2. Diagram illustrating how non-words are processed in the Interactive Activation Model. Lines represent excitatory connections between nodes (detectors).

When real words are considered, it seems plausible that the same principle of word neighbourhood density effects can be applied as with non-words. Like non-words, real words with high neighbourhood densities would have more contenders in the word level nodes, so competition between nodes will cause a delay in word recognition. However, McClelland and Rumelhart (1981) have argued that the Interactive Activation Model can actually account for both facilitatory (increasing processing speed) and inhibitory (decreasing processing speed) effects of words with high neighbourhood densities.

In the case of the facilitatory effects of high neighbourhood density, it has been proposed that a word with a large number of neighbours would activate a large number of words at the word-level nodes, which in turn send a higher number of excitatory signals to the relevant nodes in the letter level nodes through top-down processing. This means that the activated letters are reinforced and heightened so a faster response rate would be possible for words with high neighbourhood densities. For example, in the word ‘cat’, word neighbours like ‘rat’ and ‘bat’ activate the letter level nodes of ‘a’ and ‘t’. Whereas word neighbours like ‘cap’ activate the letter nodes of ‘c’ and ‘a’, and ‘cut’ activates the letter nodes of ‘c’ and ‘t’ (Figure 2-3). The word neighbours of ‘cat’ thus reinforce the letter level nodes of ‘c’, ‘a’ and ‘t’, which in turn will send heightened activation levels back to the word level nodes through bottom-up processing. Therefore a word with a large number of neighbours will reinforce activations in the system that helps it to process the target word at a faster rate.

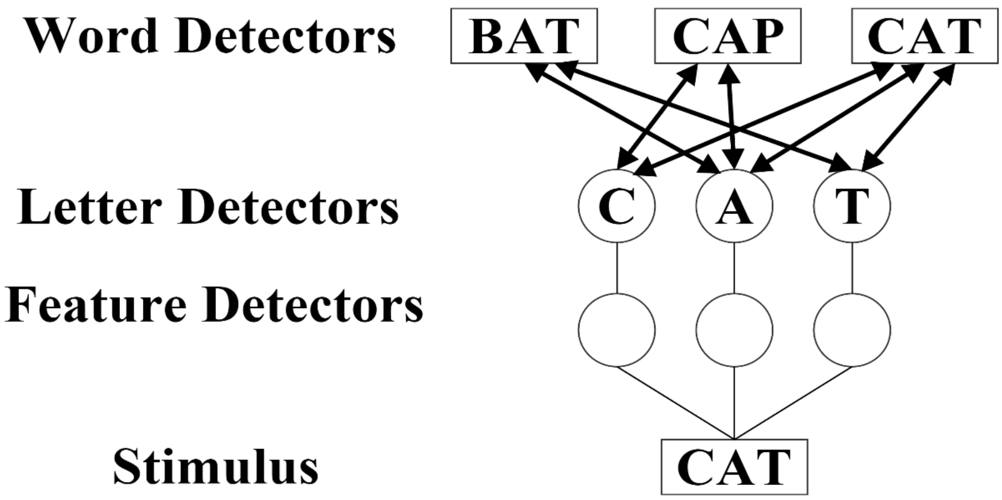

Figure 2-3. Diagram illustrating facilitatory effects of neighbourhood density on lexical processing in the Interactive Activation Model. Arrows represent excitatory activations.

For a word with a low number of neighbours or no neighbours, such as ‘banana’, the number of activations will be low, as there is no word level or letter level node reinforcement, therefore it would be harder for a word to reach its threshold and be detected. This explanation accounts for the facilitatory neighbourhood density effects of high neighbourhood density words found in lexical decision and naming tasks (Andrews, 1989, 1992; Sears, Hino, & Lupker, 1995).

Conversely, McClelland and Rumelhart (1981) mention that words with high neighbourhood densities could have inhibitory effects on lexical processing. The reason for this is that when nodes are activated at each level, they create competition between neighbouring nodes that causes activation inhibition (lateral inhibition) on all the other nodes at that level. For example, when the word ‘cat’ is presented, the word level node of ‘cat’ will laterally inhibit all the other word level nodes that contain some of the same letters, such as ‘bat’ and ‘cap’. At the same time, the word neighbours of ‘cat’ are activated and will laterally inhibit the word level node of ‘cat’ (Figure 2-4). The lateral inhibition makes it more difficult for the nodes to exceed their thresholds. The inhibition also causes interference in the lexicon because the word level nodes produce feedback to the rest of the system. The feedback occurs through top-down processing that will inhibit the relevant letter level nodes (Lim & Yap, 2010). This explanation accounts for word neighbourhood density competition effects of high neighbourhood density words in spoken word recognition tasks (Luce & Pisoni, 1998; Sommers, 1996; Vitevitch, 2002).

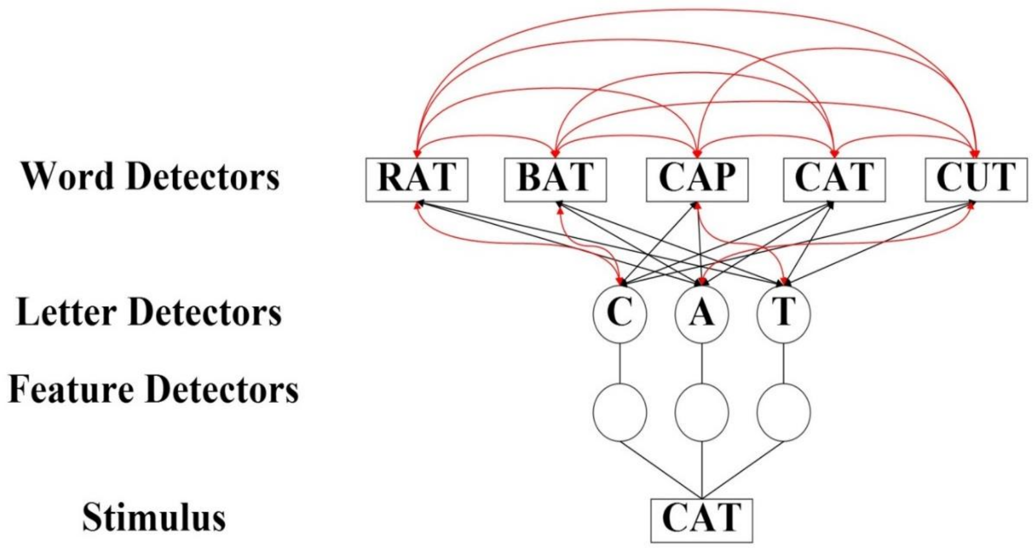

Figure 2-4. Diagram illustrating facilitatory and inhibitory effects of neighbourhood density on lexical processing in the Interactive Activation Model. Black arrows represent excitatory activations and red arrows represent inhibitory activations.

As both explanations of the facilitatory and inhibitory effects of word neighbourhood density are plausible, it is difficult to determine which of the two are used in lexical processing. McClelland and Rumelhart (1981) claimed that there is a delicate balance between the facilitatory and inhibitory effects of word neighbours during lexical processing and that this depends on each individual stimulus, as factors such as word frequency can cause changes in the activation levels as well. However, these assumptions when applied would affect non-word processing as well, because depending on how easy it is to recognise a real word based on these factors, there would be knock-on effects on non-word processing if the words in the lexicon were neighbours of the non-word. The specific non-word processing differences would therefore depend on the real words that exist within the lexicon, and their usage factors such as neighbourhood density and word frequency.

Studies in lexical development therefore need to address these factors when attempting to understand word and non-word processing in order to truly appreciate the processes that are happening within the lexicon. One way to investigate the effects of all of these factors would be to look at lexical processing over early development. By looking at the differences in processing of words which have been acquired (real words) compared to words not yet acquired (words which appear to be non-words by the individual before acquisition) as well as monitoring neighbourhood density and word frequency, it is possible to see how these factors interact with each other.

Although the Interactive Activation Model does not provide a clear explanation of how lexical processing occurs, it provides explanations of some of the mixed findings in the literature concerning both word and non-word neighbourhood density effects. Furthermore, the Interactive Activation Model incorporates connectionists' ideas on how words in the lexicon are linked and could possibly influence one another as a result of these links.

The proposal concerning connections in the lexicon helps to explore the ideas of mass connectivity. This is important when considering remote connections such as second-order neighbourhood density (neighbours of the immediate neighbours of a word), a novel idea of this thesis, which is discussed later (section 3.1.2). As there are many types of links that can exist between nodes/words, the Interactive Activation Model can account for the interactions between lexical factors as well as how neighbourhood density and word frequency interact together to affect word processing (Metsala, 1997a). For the reasons mentioned, the Interactive Activation Model is therefore used to provide a basis for understanding how lexical factors affect phone string processing for experiments in this thesis.

As the Interactive Activation Model incorporates connectionist assumptions, it provides a potential explanation for how lexical processing can change through development. However, one of the main problems is that the model does not provide a clear account of when word neighbourhood densities will cause facilitatory or inhibitory effects on processing, therefore, a more detailed model that addresses the effects of neighbourhood density is required. Furthermore, although the Interactive Activation Model has attempted to accommodate word frequency, neighbourhood density and word-non-word processing effects, there is little discussion about how these connections arise and develop in interaction with one another, especially during language acquisition in early childhood. In section 2.4, ideas from this model are the basis of a discussion of early language development and how word forms arise in the lexicon. The model also serves as a basis for developing a model which can better account for the usage factors discussed.

2.4 The Development of the Lexicon in Early Childhood; Effects of Word Usage Factors for Modelling Development of the Lexicon

In the model of language processing considered in section 2.3, it was shown that word usage factors such as word frequency and neighbourhood density play an important role in the way words are processed. Therefore it is important to understand how, when words are acquired in the lexicon during development, these usage factors change and what effect these changes have on lexical processing. In this section, the way in which new words are acquired is discussed before moving on to consider how word usage properties change and what impact they would have on child lexical development.

Based on the Interactive Activation Model, it is hypothesised that new words can be acquired by a method called generative acquisition (Vitevitch, 2008). Generative acquisition uses ideas from the connectionists approach and considers that the phonological components of a non-word (not known), such as the order of the constituent phonemes, are recognised by the individual so that when it is acquired into the lexicon, connections are created between the relevant phonemes. For example, when 'dot' is acquired, the phonemes /d/, /ɒ/ and /t/ are linked together to produce the new word-node in the lexicon (Vitevitch, 2008).

A word is considered to be acquired when it crosses its time-to-acquisition threshold, such that a word occurs frequently enough for it to be acquired into the lexicon. This illustrates why there is slow learning at the start of development followed by an acceleration of word acquisition at around age 2 (a possible vocabulary spurt) because words are encountered frequently (Ganger & Brent, 2004; Goldfield & Reznick, 1990; Mayor & Plunkett, 2010).

As each word is acquired into the lexicon, it can add to the cost or benefit of an unlearned word (McMurray, 2007), because according to connectionist models, connections between words can either be excitatory (heightens the activation of node or nodes) or inhibitory (lowers the activation of node or nodes) and therefore would affect lexical processing in different ways (McClelland & Rumelhart, 1981). Thus, it is possible that the cost or benefit of a learnt word can be determined by factors such as neighbourhood density because neighbourhood density exploits the connections that the learnt word has with other words in the lexicon. These connections help build patterns and representations during word learning and are therefore important in the processing of new words.

Vitevitch (2008) suggested that when a new word is acquired, a new node is added to the lexicon and forms connections with other word nodes that were partially activated when the new word was presented. For example the word ‘cab’, when acquired would add a new word node ‘cab’ into the lexicon and form links with words like ‘cat’ and ‘cap’ (word neighbours of ‘cab’) if these already exist in the lexicon. These connections form because the letter nodes activated by ‘cab’ activate words like ‘cat’ and ‘cap’ due to their overlapping phones. These connections between word neighbours would lead to a neighbourhood density effect on lexical processing.

This thesis builds on Vitevitch's (2008) idea that the acquisition of a word does not end once a new node is added into the lexicon. When the new node is first added, its weight and the connections between it and other nodes are weak, which means that it is harder for the newly-acquired node to be activated if the word was to be presented as input again (Munakata & McClelland, 2003). Nodes in the lexicon adapt and adjust their weights to stimuli through language exposure and learning leading to some new words being better represented in the lexicon than others (Elman, 1993, 1998). These adaptations to the lexicon are important as they minimise errors in lexical processing when stimuli are presented (Elman, 1993, 1998; Munakata & McClelland, 2003). The representation of a word in the lexicon can, therefore, vary in strength because of the number of nodes connecting to it and the activation levels of these nodes (Munakata & McClelland, 2003).

As an individual's vocabulary increases, words such as 'cat' and 'cap' would become harder to distinguish from one and another. Thus the information allocated for each node would need to increase in detail and new links between existing nodes in the system would need to be made so that the two words can be discriminated from each other (Vitevitch, 2008). Lexical networks are therefore seen as self-organising neural systems that change through adaptation to the environment and through learning (Li, Farkas, & MacWhinney, 2004). As these changes are all based on the interactivity in the lexicon, changes in one part of the network can cause changes to another part of the lexicon as the system develops (Munakata & McClelland, 2003). Therefore, it is important to consider word age-of-acquisition in lexical processing, as every time a new word is acquired changes will occur in the lexicon. By understanding these changes and when they occur, it is possible to understand how the lexicon develops and the consequences of this on the way different types of words are processed.

Early development is a crucial point for language development as this is when the neural networks in the brain are the most sensitive and prone to change (Elman, 1993). In this period there is a large amount of synaptogenesis (biological formation of connections between neurons), which starts to occur from around 8 to 9 months of age (Clancy & Finlay, 2001). Furthermore, the rapid increase in the number of words in the lexicon in childhood (vocabulary spurt) (Ganger & Brent, 2004; Goldfield & Reznick, 1990; Mayor & Plunkett, 2010), is the time when language acquisition is the most dramatic and influences the way the lexicon develops because of the large amounts of reorganisation induced within the lexicon (Ganger & Brent, 2004).

Because of the importance of word acquisition and its effects on the reorganisation of the lexicon, the age-of-acquisition of a word is another usage factor that needs to be considered when understanding lexical processing in children. As children's vocabulary spurt is a period where there are numerous changes in usage factor properties, this is a period of child development that is focused on in this thesis.

While there is considerable evidence that a vocabulary spurt exists, there is also an argument that states that many children have a constant rate of word acquisition. For example in the study by Ganger and Brent (2004), only 4 out of 20 children showed evidence of a vocabulary spurt. As a result of this, the computational work in this thesis looks at the number of words acquired over age and which ages causes the largest lexical changes. So to add to the usage factors of interest in this thesis, word age-of-acquisition (when a string of sounds change from being a non-word to a word) is also considered for the implications it could have in models of lexical processing. In the following section, the link between word age-of-acquisition and neighbourhood density is made more explicit and the problems in methodology in some studies are discussed.

2.4.1 *Studies of Word Age-of-Acquisition Effects in Development*

Differences have been reported in processing that depends on word age-of-acquisition (Charles-Luce & Luce, 1990, 1995; Storkel & Morisette, 2002; Storkel, 2004). There is a significant relationship between age-of-acquisition and word properties, as words that are acquired earlier in life have higher word frequencies and neighbourhood densities (Storkel, 2004). Computational studies on number of word neighbours at different ages in children's receptive (age 1.1-1.9 years) and expressive vocabularies (age 5-7 years) have also shown that young children have sparser word neighbourhoods compared to older children and adults (Charles-Luce & Luce, 1990, 1995).

The reason why word neighbourhood density depends on age is because word neighbour calculations are based on the words known in the lexicon (Luce & Pisoni, 1998). As children acquire more words, word neighbourhood density properties of words would shift depending on the properties of the new word acquired, so a word with few neighbours in early childhood can have more neighbours in later development and adulthood (Storkel & Morisette, 2002).

It is possible that a low neighbourhood density word in infancy may become a high neighbourhood density word after the vocabulary spurt. For example, using Storkel and Hoover's (2010) online calculator for word neighbourhood density, it was found that the word 'cut' has six word neighbours and the word 'car' has 10 word neighbours in childhood (based on child corpus data). Yet, these become 13 and 10 respectively in adulthood (based on adult corpus data). In the case of 'cut', this word has a low neighbourhood density in childhood compared to 'car', however when new words are acquired through development, shifts occurred in the lexicon and the word 'cut' eventually ends up having more neighbours than 'car' in adulthood. Based on this observation, it is necessary to consider word neighbourhood densities using the age-appropriate word databases when testing for neighbourhood density effects.

There are limitations in the methodology of many studies in the literature that make it hard to use age-appropriate word databases to calculate word neighbourhood density. As this thesis addressed the way neighbourhood density effects change in childhood, word databases from children rather than from adults were needed in order to obtain children's neighbourhood density measures. The methodology used by psychologists in the field to calculate age-appropriate neighbourhood density is discussed in Chapter 3 and an approach towards improving the methodology is proposed.

2.4.2 *Studies on Word Neighbourhood Density Effects in Development*

It is difficult to obtain measures other than speech from young children. Therefore, many of the studies in the literature on neighbourhood density effects in early development are experiments on language production. Vitevitch and Sommers (2003) studied neighbourhood density effects in a tip-of-the-tongue elicitation task using younger (under 65 years old) and older (over 65 years old) adults. Participants were required to retrieve a word from memory that best matched the definition provided by the experimenter. It was found that the younger participants were able to produce words with high neighbourhood densities faster than those with low neighbourhood densities, whereas there was no significant effect of neighbourhood density for older adults.

Arnold et al. (2005) looked at a younger sample (3 to 5 years old children). They found the opposite effect of neighbourhood density to that reported by

Vitevitch and Sommers (2003). Children with typical language development and children who stutter were asked to name pictures. In both groups of children, it was found that naming was more accurate for words with low neighbourhood densities than words with high neighbourhood densities.

The results from the two studies therefore indicate that there is an effect of age on neighbourhood density. This highlights another factor to be considered when looking at neighbourhood density. Thus, it is possible that not only are there word age-of-acquisition and word neighbourhood density effects on lexical processing, but that age itself is another determinant of performance. However, it should be noted that both of these studies used adult lexicon databases and did not consider how neighbourhood density changes over ages. It is essential to have age-appropriate calculators so that neighbourhood density results for different ages are not biased (see chapter 3 for further consideration of this). Both the findings of Vitevitch and Sommers (2003) and Arnold et al. (2005) suffer from this limitation.

Other studies have used children's lexical databases to calculate neighbourhood densities. They show effects of word neighbourhood density and age. Experiments that use adult ratings of word age-of-acquisition data to determine word neighbourhood density statistics in children, have reported contradictory effects of words with low neighbourhood densities. For instance, in a word repetition experiment, it was found that early-acquired words (acquired before 4.5 years old) with low neighbourhood densities were repeated more accurately than words with high neighbourhood densities (Garlock et al., 2001). The effect was consistent across younger (pre-school and kindergarten children) and older children (first-, and second-graders) as well as adults (Garlock et al., 2001). However with later-acquired words (acquired after 4.5 years old), the young age group was the only one that showed no effects of word neighbourhood density on word repetition accuracy; the other two age groups still showed that words with low neighbourhood density had improved performance. This supports the idea that word age-of-acquisition, word neighbourhood density and participant age are all influential in lexical processing, and that there are possible interactions between these factors as well.

Metsala (1997a) used a gating task to test the effects of word neighbourhood density and frequency for participants of different ages. In the task, participants listened to words where amounts of acoustic-phonetic information varied (i.e. from onset to different points in the test word). In children aged 7, 9 and 11 years, and adults, it was shown that as the participants' ages increased, less acoustic-phonetic information was required for them to identify high frequency words with low neighbourhood densities. Furthermore, the same age-dependent effect was reported in low frequency words with low and high neighbourhood densities, as children aged 7 and 9 took longer to identify these words compared to older children and adults. The findings from the study therefore show that there is a word frequency by neighbourhood density interaction and emphasises that word frequency can also affect lexical processing.

2.4.3 *Theoretical accounts of Neighbourhood Density Effects on Lexical Processing*

This section considers how neighbourhood density effects in lexical processing can be incorporated into the Interactive Activation Model (McClelland

& Rumelhart, 1981; Rumelhart & McClelland, 1982). There are two proposals regarding neighbourhood density effects on lexical processing: Lexical Competition Theory (Grainger & Jacobs, 1993; McClelland & Rumelhart, 1981) and Global Activation Theory (Grainger & Jacobs, 1996).

The Lexical Competition Theory predicts that high neighbourhood density words inhibit word retrieval (Grainger & Jacobs, 1993). It maintains that when searching for a word, other words that have similar properties, such as shared phonemes, are activated at the same time. Similar words compete with each other until the one with the highest activation (usually the target word) is selected for output. As a result of this best match strategy of retrieval, words that have more neighbours have more competitors to choose between. Thus they take longer to be retrieved from the lexicon because the individual has to process a large number of words before the target word is identified.

In contrast the Global Activation Theory takes a top-down approach to word retrieval and predicts that high neighbourhood densities facilitate word retrieval (Grainger & Jacobs, 1996). This theory maintains that words with similar units, such as shared phonemes, contribute together to produce a summed activation level which leads to higher levels of activity. The summed activation level helps individuals to retrieve articulatory units (speech sounds) of the target word, therefore the more neighbours that a word has, the higher the activation level and thus the faster the word can be retrieved.

These two views aid understanding of how neighbourhood density can lead to facilitatory and inhibitory effects, as reported in different experiments. However, out of the two theories, this thesis argues that the Global Activation Theory (Grainger & Jacobs, 1996) is a better account of neighbourhood density effects in child language development. The reason for this is because early childhood is a time where there is the largest increase in vocabulary, thus a facilitatory effect would be more beneficial for language development as this allows more words to be learnt than an inhibitory effect. Nonetheless, these theories are limited when it comes to explaining developmental effects because mappings and connections between words and non-words change over development, as demonstrated in studies in the literature that shows age and word age-of-acquisition effects across age groups.

In the next chapter, a computational analysis is conducted that obtains neighbourhood density statistics over development, i.e. how the number of high and low density word neighbours changes as age increases. The results illustrate the changes in the lexicon that occur in childhood and allow the creation of materials which can be used in the experimental studies. The studies were designed to test these theories of neighbourhood density effects and extend them to account for developmental influences.

2.4.4 *Factor of Word and Non-words*

A factor that arises from the first computational analysis (Chapter 3) and experiment (Chapter 4), and one that has been discussed earlier in this chapter is whether a string of phones is treated by a child as a word or not. It has already been argued that it is important to look at how a phone string that is not present in the lexicon (treated as a non-word) becomes a known word that is added to the lexicon as this can impact the neighbourhood density of other words in the lexicon.

A way that new words can be acquired has already been outlined (generative acquisition) that could be added to connectionist models. Vitevitch (2008) favours the generative acquisition account because it is biologically-plausible (marries with connectionist models of language processing). He suggested that when a new word is acquired, a new node is added into the lexicon that then forms connections with other word nodes. However, in his work he did not indicate the process by which these new words arise. As the view proposed by Vitevitch (2008) is incomplete, this thesis aims to further develop his ideas in order to provide the basis for a more comprehensive model.

If the Generative Acquisition Theory is a good account of word acquisition, then processing of phone strings treated as non-words (words not yet acquired) should be affected by existing words in the lexicon, in particular word neighbours that have similar phonological patterns to the non-word. The conversion of non-words to words should be facilitated when the non-word string shares some phonological patterns with other words as these connections already exist and do not need to be built. Based on this argument it is thus possible that strings that are non-words at one age that have regularly-used phoneme combinations would improve processing speed because it can use the phonological patterns it shares with words in the lexicon. This means that a non-word with a large number of existing neighbours in the lexicon could potentially be easier to acquire than one with few neighbours.

2.4.4.1 **Studies on Word and Non-word Neighbourhood Density Effects**

Luce and Pisoni (1998) used an auditory lexical decision task to study neighbourhood density effects of non-words and words. They obtained adults' reaction times to words and non-words with different neighbourhood densities. Words with high neighbourhood densities were reacted to slower than words with low neighbourhood density. Similarly, non-words with many neighbours were responded to more slowly than non-words with fewer neighbours. This illustrated that neighbourhood density effects are consistent across words and non-words. However the study was only conducted on adults. Since adults do not acquire words at the rates children do, the effects of neighbourhood density demonstrated in this study do not comprehensively explore the way a phone string changes from a non-word to a word which is a process that occurs predominantly in childhood.

Children also show that non-words have neighbourhood density effects. Storkel and Lee (2011) found that in a non-word learning task children aged 4 were more accurate in pairing learnt non-words with the correct pictures if they had a low neighbourhood density than if they had a high neighbourhood density. However, when participants were retested one week later for retention of the non-words, it was found that non-words with high neighbourhood densities showed improvements in performance without additional training, whereas low neighbourhood density non-words demonstrated more of a decrease in performance although this was not statistically significant. Hoover et al., (2010) also tested children's ability to learn non-words. They used within-story and across-story manipulations for non-word learning and found that preschool children (3-5 years old) learned non-words with high neighbourhood densities better than non-words with low neighbourhood densities across stories, but learned low neighbourhood density words better within stories.

These findings illustrate the different neighbourhood density effects when non-word phone strings take on lexical status and show that the effects may depend on task. It appears that irrespective of the direction of the neighbourhood density effects on non-word processing and acquisition, there is clear evidence from these studies that neighbourhood density influences performance. Therefore, from the literature it appears that the Generative Acquisition Theory for non-word acquisition is supported. However, the inconsistent results on the effects of neighbourhood density of non-words across tasks makes it difficult to establish whether phone strings with few or many neighbours aid performance.

The neighbourhood density of non-words could change over age as new words are acquired, in a similar way to what happens with words. Therefore when a phone string that represents a word which is not yet known (regarded as a non-word by a child) is subsequently learned and is added to the lexicon (i.e. becomes a word), all the corresponding word and non-word first- and second-order neighbourhood densities will change accordingly. These dynamic changes would be expected to cause differences in word and non-word processing. Therefore, it is important to consider word and non-word neighbourhood density statistic changes over ages.

2.4.4.2 **Theoretical accounts of Word and Non-word Processing**

Vitevitch and Luce (1998) used the Grossberg, Boardman, and Cohen (1997) framework of spoken word recognition, termed the Adaptive Resonance Theory, to explain the differences between word and non-word processing. According to Grossberg et al.'s (1997) framework, word processing uses a combination of bottom-up and top-down processes. For example when a word is heard, the phonemes of that word are contained as items in working memory and they are fed into the short-term memory through bottom-up analysis. Meanwhile short-term memory is affected by top-down influences that seek to put these phonemes into chunks and attempt to match them to a known word for the individual. It is considered that phoneme clusters that are encountered more frequently in the language lead to greater activations in the top-down process as there are more words in the lexicon with the same phonological patterns. This results in phonological patterns that are familiar, thus speeding up processing. The use of both bottom-up and top-down processing is referred to as a matching process.

Using the ideas from Grossberg et al., (1997), Vitevitch and Luce (1998) suggested that non-words are processed at a sublexical level where phonemes are processed bottom-up as phonemes or chunks that are fed into the matching process. For example for the non-word ‘geg’, the phonemes /g/, /**ɛ**/ and /g/ are fed up into working memory and the matching process tries to match these to any existing words in the lexicon. In contrast, words that are known are processed at a lexical level and are matched as one unit; the word ‘cat’ would be processed as the whole word /k**æ**t/ rather than as separate phonemes. This is illustrated in Figure 2-5.

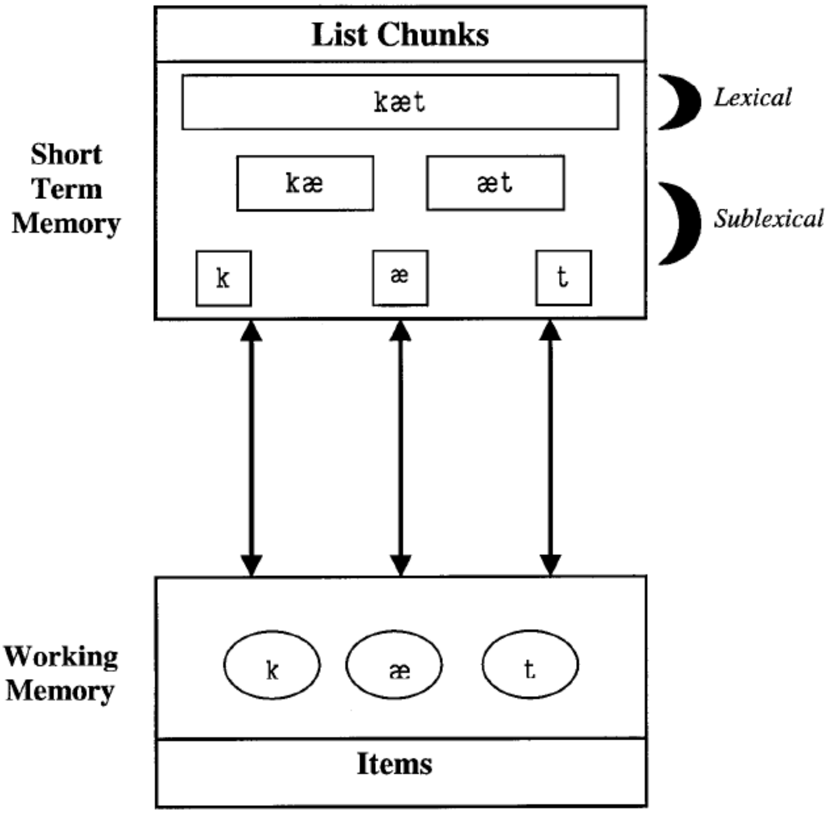

Figure 2-5. A schematic diagram of a framework for spoken word recognition based on Adaptive Resonance Theory (retrieved from Vitevitch and Luce (1999)). Non-words are processed sublexically as separate phonemes and fed into the matching process whereas known words are processed lexically and are sent as a whole unit into the matching process.

As a result of the specific type of processing used, it is proposed that non-words with high neighbourhood densities are processed more quickly than non-words with low neighbourhood densities as the phoneme chunks cause greater activation because of their high frequency of occurrence in speech. In contrast, words with high neighbourhood density would be processed slower than words with low neighbourhood densities as they experience lateral inhibition (competition between neighbouring nodes) from competing lexical items (other word nodes).

Developing the ideas of Vitevitch and Luce (1999), a Generative Acquisition Hypothesis Processing Shift Model is proposed in this thesis to help explain how non-words become words in an individual's lexicon (Figure 2-6). The Generative Acquisition Hypothesis Processing Shift Model uses the Interactive Activation Model as a basis in explaining the relationship between phonemes and words in the lexicon and how connections between nodes affect lexical processing. The generative acquisition hypothesis is embedded into the Interactive Activation Model so that developmental changes can be accounted for. Finally, the Generative Acquisition Hypothesis Processing Shift Model helps explain why there are processing differences between words and non-words and why the acquisition of new words has an effect on existing words and how words are processed.

The Generative Acquisition Hypothesis Processing Shift Model adds to the generative acquisition hypothesis by proposing that non-words are acquired and become words when word properties, such as word frequency and semantic representation, are established for the target phone string through learning. Based on the ideas that have been discussed and theories of memory, the model suggests that the shift of words from a sublexical to a lexical level is through word repetition (based on word frequency in language) and contextual representation (semantics). These word learning processes happen automatically as a child is exposed to a phone string repeatedly, but the rate at which a non-word becomes a word depends on how much attention is given to learning the phone string and the individual's learning threshold level. That is the degree to which repetition, attention and semantic links are required before an individual recognises the phone string is important, accesses a meaning and should be acquired.

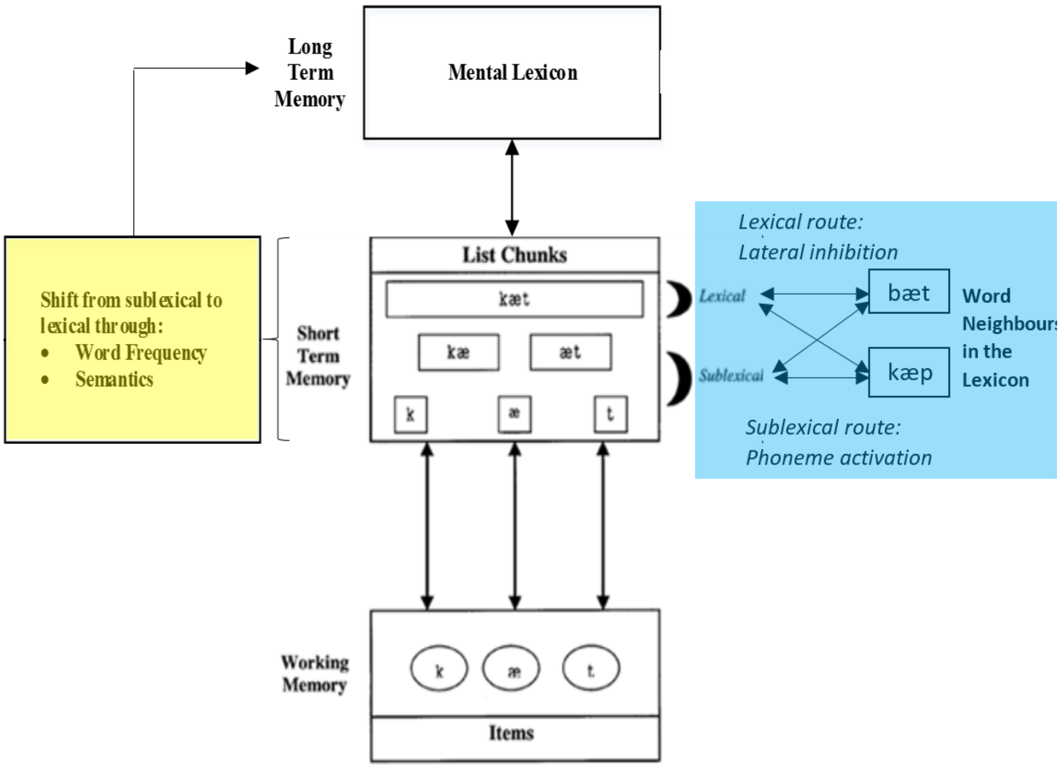

Figure 2-6. The integrated Generative Acquisition Hypothesis Processing Shift Model of non-word and word acquisition and processing. The part highlighted in yellow is developed from the generative acquisition hypothesis and the part highlighted in blue is developed from the Interactive Activation Model. Non-words are processed sublexically until enough word properties are established for the non-word to become a word. Once a non-word is acquired into the mental lexicon it is then processed lexically. Word neighbours in the lexicon aid the sublexical route through phoneme activation, but hinder the lexical route through lateral inhibition.

In this account, a phone string is processed phonemically until it occurs frequently enough and has formed strong enough semantic links with a contextual representation so that it then becomes a word in the mental lexicon by a generative acquisition process. Once a word is stored in the mental lexicon it can then be processed semantically using top-down information instead of relying on bottom-up information alone. Overall processing has shifted from sublexical processing to lexical processing.

Based on the idea of a processing shift, non-words which are not acquired into the lexicon, will stay as a non-word and will be processed sublexically. This could be because the non-word is a true non-word and does not exist within the English dictionary, or it does not occur frequently enough or have any semantic representation for it to shift from its non-word status to a word status.

With the Generative Acquisition Hypothesis Processing Shift Model it is possible to predict what neighbourhood density effects on words and non-words should occur during spoken production because words and non-words are processed differently. The computational analysis in Chapter 5 therefore aims to generate new word and non-word stimuli for testing in order to examine the ideas from the Processing Shift Model, i.e. that words are processed lexically and non-words are processed sublexically.

In the case of words that are processed lexically, top-down analysis happens and the target word is matched to words in the lexicon as whole units rather than from their separate phonemes. Thus, when a target word is presented, all the words in the lexicon which are similar to it (its word neighbours) would be activated. Based on ideas from the Interactive Activation Model (McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982), top-down analysis would predict that a word with a high number of word neighbours would take longer to be recognised and processed because other word nodes cause lateral inhibition (McClelland & Rumelhart, 1981). Lateral inhibition happens when the neighbouring representations (in this case word neighbours) are activated and compete for highest activation level with the target word's node in the lexicon. For example, when the target word 'cat' is presented, its word neighbours like 'rat', 'bat', 'cap' and 'cut' to mention a few, would be activated as well (Figure 2-4).

Top-down influences occur as word processing traverses down each level eventually reaching the phoneme level, allowing checks to be made at every level. When there are many neighbours at these processing levels, the competition between words make it more difficult for the target node to reach its activation threshold so processing takes longer. This explains why in the literature, many studies have found neighbourhood density competition effects for high neighbourhood density words in spoken word recognition tasks (Luce & Pisoni, 1998; Sommers, 1996; Vitevitch, 2002).

Conversely, for non-words, the Processing Shift Model assumes that these stimuli are processed sublexically, requiring bottom-up analysis. When a string of phones that is a non-word is presented, its phonemes eventually feed up to the lexical level. When analysis is completed, matches with existing word nodes can be determined. As the stimulus itself is a non-word it will not match an item in the lexicon. Consequently, any words that are neighbours of the target non-word will not compete for processing with the non-word.

Based on the work by Vitevitch and Luce (1998), it is proposed that the influence of varying number of neighbours on non-words is as follows. Phoneme chunks are shared when a non-word has a neighbour that is a word. The chunks of the non-word are processed sublexically, and activate words that share the chunk via the sublexical route. Non-words that have a large number of neighbours in the lexicon will receive more activation from word neighbours via this route than non-words with a low number of word neighbours. For example the non-word 'dat', has a lot of neighbours like 'cat', 'rat' and 'bat', so when 'dat' is presented, the phoneme combinations of /a/ and /t/ will cause numerous activations in the lexicon because there are a lot of words with this phoneme chunk in the lexicon. Consequently, an individual can use the ensuing activations from these many words to aid the processing of the non-word as the words that share the common phoneme chunks reinforce how the non-word should be produced. This offers an explanation to why non-words with high neighbourhood density are processed more accurately than non-words with low neighbourhood density.

2.4.4.3 **Summary**

This chapter identified the Interactive Activation Model (McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982) as the preferred explanation for neighbourhood density effects. It was argued that the generative acquisition hypothesis (Vitevitch, 2008) as an adjunct to the Interactive Activation Model offered a plausible explanation about how new words are acquired into the lexicon. It has been argued here that a structure to control the interactive activation/generative acquisition adjunct is needed (the processing shift component; Vitevitch and Luce's (1999)) to account for differences between word and non-word processing. Two limitations about the Processing Shift Model as it pertains to the current thesis are: 1) it is not a connectionist model; and 2) in itself, it does not account for developmental changes as phone strings change from non-words to words. However, when the Processing Shift Model is combined with the generative acquisition component (Vitevitch, 2008) in combination with the Interactive Activation Model, it may be possible to account for these limitations. This is the model, the Generative Acquisition Hypothesis Processing Shift model, put forward and developed in this thesis.

Fundamentally, the Generative Acquisition Hypothesis Processing Shift Model helps explain how words not yet acquired are processed sublexically until they occur frequently enough and have structural representation (semantics) for them to be acquired into the lexicon, therefore forming connections with existing words in the lexicon. When words are added into the lexicon, they form links with their word neighbours as they share the same phonemes (based on the Interactive Activation Model). As a result of these links and the word status of the new word, processing becomes lexical. The Generative Acquisition Hypothesis Processing Shift Model therefore provides a possible explanatory framework for why processing differences occur over development in words and non-words as a result of their phone string neighbours.

The studies and theories discussed in this chapter have focus on language perception. However, the aim of this thesis is to take these ideas forward to explain how they can affect speech production. It has been argued that although language perception and production represent two different systems, the representations of phonological segments, word forms and semantic information used in both are similar. Therefore it can be hypothesised that variables which affect language perception affect language production as well (Vitevitch, Armbrüster, & Chu, 2004). This can be demonstrated in studies examining word neighbourhood density, where the same effects of neighbourhood density are seen both in lexical decision (word perception) and word repetition tasks (word production) (Luce & Pisoni, 1998; Ziegler et al., 2003). In fact, many models of language production are based on connectionist models, involving the ideas of spreading activations in the lexical network which explains why language perception and production work with the same core principles (Dell, Chang, & Griffin, 1999).

It has also been argued that speech production is constrained by perceptual factors as the aim of speech is to communicate so that produced language is available for perception (Cutler, 1987). This is an important point to consider because if speech is constrained by perceptual factors, then younger children would have more constraints in their speech compared to older children due to the language they are exposed to (e.g. speakers speak to children more simply than to adults). This could possibly explain the processing differences between words and non-words, as words known by the child are within their perceptual constraints whereas non-words are not.

Based on the arguments made it is hypothesised that the Generative Acquisition Hypothesis Processing Shift Model can be applied to language production as well as perception and can help to predict how lexical factors such as neighbourhood density and word/non-word status affect lexical processing.

3 Chapter 3: Computational Analysis on the Development of Lexical Networks

3.1 Introduction

As shown in the previous chapter, word usage factors such as word frequency, age-of-acquisition and neighbourhood density, have an effect on the way words are processed. More importantly, research into word neighbourhood density has played a vital role in the development of lexical models and in understanding the processing strategies used for language (Charles-Luce & Luce, 1995; Coady & Aslin, 2003; Goldinger et al., 1989; Luce & Pisoni, 1998). For this chapter, the factor of word-non-word status would not yet be investigated, as this chapter focuses on how neighbourhood density statistics of words change over development.

By studying word neighbourhood density, it is possible to evaluate how words are acquired and represented in the lexicon. In particular, by understanding how lexical networks develop over age, associations can be made between language acquisition and how this relates to the changes in the mapping of words within the lexicon.

As discussed, studies on the effects of word neighbourhood density on word recognition and production have provided contradictory findings. On the one hand, studies have shown inhibitory effects of neighbourhood density in auditory lexical decision and word repetition tasks where words with high neighbourhood densities were reacted to at a slower rate than words with low neighbourhood densities (Luce & Pisoni, 1998; Vitevitch, 2002; Ziegler et al., 2003). On the other hand, other studies have found facilitatory effects of neighbourhood density in lexical decision, word naming and delayed naming tasks where words with high neighbourhood densities were responded to faster than words with low neighbourhood densities (Andrews, 1989, 1992; Sears et al., 1995). Although the latter studies showed a facilitatory effect of neighbourhood density, it can be argued that this is only present for low frequency, high neighbourhood density words.

The problem present in many of the studies on the effects of neighbourhood density is that they used materials that were appropriate for adult samples, but which were not useful for studying the development of lexical networks in childhood. As language development increases rapidly in the early years of life (including the vocabulary spurt), it is important to study neighbourhood density changes and their effects using appropriate material obtained during this period to properly understand how lexical networks are formed and how they develop (Ganger & Brent, 2004).

Some studies in the literature have tried to account for the differences between adult and child word neighbourhood densities by using age-of-acquisition data so that the appropriate neighbourhood density statistics can be calculated (Garlock et al., 2001; Metsala, 1997a, 1997b; Storkel & Hoover, 2010). However, like studies conducted on adults, the findings from these studies show contradictory effects of neighbourhood density on lexical processing.

The aim of this study is therefore to use an improved methodology to analyse the neighbourhood density changes in early childhood, in order to provide insights into how lexical networks develop at this age. A further consideration that is important in helping to understand the changes in the lexical mappings that occur is to extend research beyond adjacent neighbours (first-order neighbours).

3.1.1 *Methodology for Calculating Age-Appropriate Neighbourhood Density*

Studies in the literature attempt to account for age effects in neighbourhood density statistics. However, limited attention has been given as to whether the databases they used were relevant to children (Garlock et al., 2001; Metsala, 1997a, 1997b; Storkel & Hoover, 2010). In order to determine what words exist within children's lexicons, these studies first obtain word age-of-acquisition data so that they know at whether a word has been acquired by a given age. Using these statistics, it is possible to determine which words should be in the lexicon by a certain age (for example age 9). Computational neighbourhood density calculators can then determine the number of neighbours of a word using the age-appropriate lexicon. The computation of neighbourhood statistics is the same as those used with adult lexical databases. Figure 3-1 summarizes the procedure.

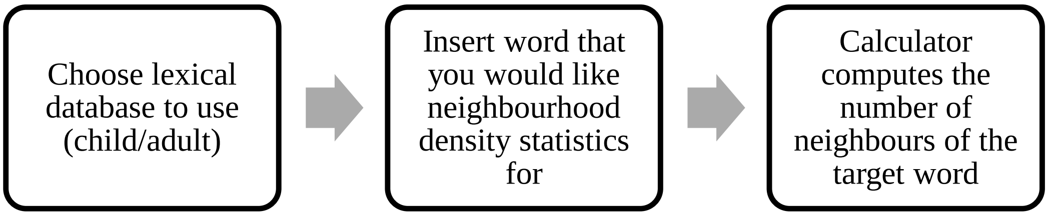

Figure 3-1. Process in obtaining word neighbourhood density statistics that employ different lexical databases.

One method used to determine age-of-acquisition data is to ask adults to indicate the age words in a set were acquired. Those words acquired before a specified age (for example age 9) can then be used to calculate child word neighbourhood density statistics (Garlock et al., 2001; Metsala, 1997a, 1997b). When this procedure is used, the neighbourhood density statistics obtained are more appropriate for children than statistics obtained using adult databases. The limitation with this method is in the way age-of-acquisition of words was estimated, as it relies on participants' memory about when they consider they acquired the words. This can be subjective and may be inaccurate.

Another approach used in the calculation of child neighbourhood density statistics is to use children's speech data to see what words are used at different ages. This was the approach of Storkel and Hoover (2010). They combined two language corpora, one from words produced by kindergarten children (Kolson, 1961), and another from words produced by first grade children (Moe, Hopkins, & Rush, 1982). They then calculated child neighbourhood density statistics from the combined database. With this method, the data used should be more accurate, as they were obtained directly from children's utterances. However, as the method only used two language corpora, they may still not be representative of children's lexicons. A more suitable way to create a database of children's speech would be to use the extensive Child Language Data Exchange System (CHILDES) database (MacWhinney, 2000). The CHILDES database allows researchers to upload children's speech transcripts. Therefore, a large and wide range of speech data (e.g. speech data from different social groups) is available.

Available age-appropriate language corpora for children at different ages are limited. Consequently, the neighbourhood density statistics used in experiments may still not be precise enough to determine neighbourhood density effects in children's word processing. This may be particularly true during the vocabulary–spurt period. As the lexicon changes rapidly in the early years of life, neighbourhood statistics should be estimated for the age of the participants being tested to ensure that the results are reliable.

Fortunately, the CHILDES database is large and has transcriptions from children across a broad range of ages. This makes it possible to split the speech data into age ranges and obtain lists of words that children know in each range. This way, more appropriate neighbourhood density statistics are obtained for assessing children at different ages. For this reason, the studies in this thesis used the CHILDES database to calculate word neighbourhood densities for different age ranges. By calculating neighbourhood density more precisely using age-of-acquisition data obtained from children's utterances, a good indication can be obtained about how neighbourhood density changes over age, and appropriate materials and procedures can be designed for testing children at different ages.

3.1.2 *Extension of neighbourhood density calculations to second-order neighbours*

As previously mentioned, a novel aspect of this thesis is to extend neighbourhood density calculations to remote neighbours. Based on connectionist approaches, it is assumed that there is massive connectivity in the lexicon, which means that connections for a target word should not be restricted to its immediate neighbours as there would be word connections that extend from the immediate neighbours too, and so on. To investigate the extent of lexical networks, second-order neighbours can be examined (word neighbours of first-order neighbours) (Figure 3-2). This should provide a better picture of lexical networks and their growth and if higher order neighbourhood density effects occur, then this would support the assumptions made by connectionist modellers. In the case of this thesis, the factor of second-order neighbourhood density is studied to test this idea.

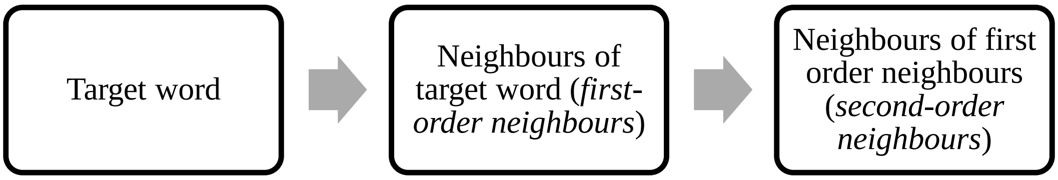

Figure 3-2. How first-order and second-order neighbours are determined.

For the first study, computational analyses were made on databases analysed according to age-of-acquisition and neighbourhood density measures so that the change in first- and second-order neighbourhood densities over age could be examined. By using age-of-acquisition databases, neighbourhood densities can be worked out based on the words children know at selected ages. The data obtained in the computational analysis can then be used to design materials for production testing so that neighbourhood density effects on lexical production can be investigated. Doing this, it is possible to test whether the Global Activation Theory (Grainger & Jacobs, 1996), provides an acceptable account of neighbourhood density effects. It was predicted that the number of first- and second-order neighbourhood density words would increase as age increases because new vocabulary items are acquired over development.

3.2 Computational Analyses One

3.2.1 *Overview*

Computational analyses were performed to assess what effects the number of first- and second-order word neighbours of those words that are known at the particular stage of development have on children's early lexical development. The number of words children know as age increases is reported in Analysis One. Using information about the words which the children know at different ages, first- and second-order neighbourhood densities were then calculated and their incidence statistics reported (Analyses Two and Three).

3.2.2 *Method*

3.2.2.1 **Materials.**

Data from various linguistic databases (indicated below) were evaluated for use in the computational analyses. The Child Language Data Exchange System (CHILDES) database (MacWhinney, 2000) was chosen because it is a database that allows researchers to upload children's speech transcripts, leading to a wide range of speech data being available. This is crucial as the more speech data that are available, the more accurate the computational analyses are in terms of calculating neighbourhood density, as the speech data give an indication of which words children have acquired at different ages.

The lexical database of De Cara and Goswami (2002) was chosen because it allows the calculation of all the phonological neighbours when a word is entered. This lexical database is also useful as it provides spoken word frequencies which are vital for controlling word frequency of the materials used for testing in the experiments.

3.2.2.1.1 Child Language Data Exchange System (CHILDES) database (MacWhinney, 2000)

The CHILDES database contains transcripts of conversations between children and their care-givers. The ages of the children who participated are given in months. This is the most widely used resource in child language research.

3.2.2.1.2 Lexical database with computerised routines to provide extended lists of phonological neighbours (De Cara & Goswami, 2002)

The lexical database of De Cara and Goswami (2002) contains 4,086 English monosyllabic words (including both function and content words), their phonetic codes, spoken frequency (obtained from the CELEX Lexical Database measure (Baayen, Piepenbrock, & Gulikers, 1995)), and their age-of-acquisition [based on Gilhooly and Logie's (1980) data on adults] was employed. Spoken frequency of a word is measured by its occurrence per million within a 17.9 million spoken word corpus. The phonetic codes are presented in a 9-slot sequence with one phoneme per slot. As the words in the database are monosyllabic, the number of phonemes does not exceed the 9-slot sequence. By inserting the 9-slot phonetic code into the computerised routine a list of all the phonological neighbours related to the target word is returned.

The computerised routine provides two measures of phonological neighbourhood density: OVC (onset, vowel, coda) metric and Ph+/-1 metric. The OVC metric groups the vowel and coda phoneme changes together under the superordinate category of rime, so that a word with changes in both the vowel and coda (one dimension) can also be identified as a neighbour. On the other hand, the Ph+/-1 metric is the standard one where a word is defined as a neighbour when there is only a change in one phoneme. For each metric, single phoneme substitution, deletion or addition can happen in three different areas of the syllables in a word: 1) initial consonant or consonant cluster of a word (onset); 2) vowel; or 3) final consonant or final consonant cluster of a word (coda). These are named RN, CN and LN neighbours respectively.

3.2.2.1.3 The Computerized Language Analysis (CLAN) program from the CHILDES database (MacWhinney, 2000)

The Computerized Language Analysis (CLAN) program from the CHILDES database was used to analyse the transcripts obtained from CHILDES so that a list of words known by the children at different ages could be generated. To analyse the data produced by CLAN (words), MATLAB programs were written so that the words generated could feed into the lexical database (De Cara & Goswami, 2002) and consequently all the phonological neighbours could be calculated.

3.2.2.2 **Procedure**

A total of 5,780 American children's real-time (same child at different times) and apparent-time (different children at different times) conversation transcripts were obtained from the CHILDES database. American children's data were selected in order to provide a large number of transcripts for analysis (as American children's data are the most numerous in CHILDES). Transcripts with more than one child in the conversation were filtered out to keep the materials constant. The transcripts were grouped into their relevant age groups based on the child's age in months (range 5 months to 16 years old).

To ensure that the same number of transcript files was used from each age group, the median number of transcript files was calculated using Excel (*Mdn* = 23). Age groups with less than 23 transcript files were removed from the analysis, leaving 59 age groups (range 9 months to 7 years 6 months) and a total of 1,357 transcript files for the computational analysis. Age groups in this range were defined as lasting 1 month, e.g. 9-10 months (named 9 month group), 10-11 months (named 11 month group). Transcript files with more than 23 for each age group had 23 selected at random. For the analysis of the number of words known in different age groups, all 59 age groups were explored. However as the age intervals of the transcripts available varied across age, it was decided in order to keep the analysis consistent, that the neighbourhood density calculations be only done every 6 months from age 1 to 7 years and 6 months. It should be noted that the age groups are not continuous as not all of them had 23 transcript files, thus the final age groups considered in the neighbourhood density analysis are: 1 year, 1 year and 6 months, 2 years, 2 years and 6 months, 3 years, 3 years and 6 months, 4 years, 4 years and 6 months, 5 years, 5 years and 6 months and 7 years and 6 months.

Using CLAN, children's transcript files were analysed so that only the words spoken by the children were selected (not those of the interlocutor). The speech data from each individual child's transcript file were saved into an Excel file. This enabled the list of words spoken by each child to be filtered by a purpose-written MATLAB program so that only those words that exist within the lexical database remained (Program 1).

3.2.2.2.1 Program 1 (Appendix A, Figure 3-3).

The program read through the Excel files of the word lists and checked each word to see if it occurred in the lexical database of De Cara and Goswami (2002) so that the computerised routine that comes with the database could be run and word neighbours calculated. Those words in the word lists that matched those in the lexical database were written into a new Excel file.

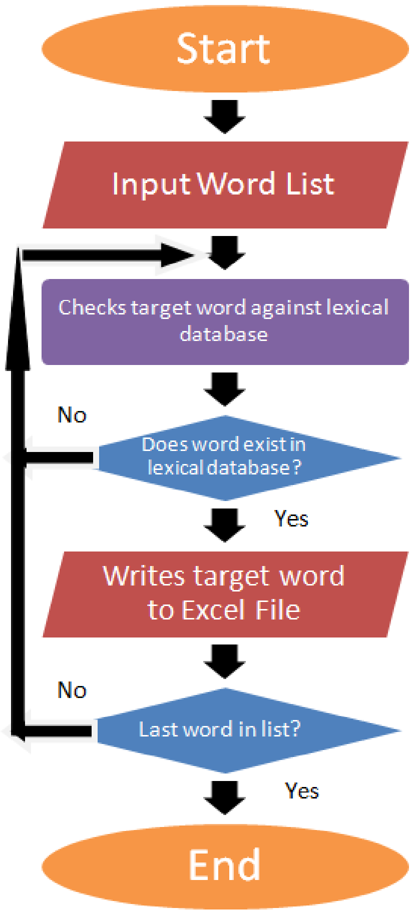

Figure 3-3. Process flow chart of Program 1. The program loops through the word list and checks every word. Notice that procedures are defined by square boxes, Input/Output by parallelograms, and Start/End by oval boxes.

Once words that were in the lexical database were obtained using Program 1, a second purpose-written MATLAB program (Program 2) obtained the number of effective and rejected neighbours of the target words in the lists. Effective neighbours are the word neighbours that children know at the selected age and rejected neighbours are the word neighbours that the children do not know at the selected age (i.e. words which are considered to be non-words for children at that age). For word lists of each individual child at each age, only those words that the age-of-acquisition data indicated were known (effective) were selected as phonological neighbours of those words.

3.2.2.2.2 Program 2 (Appendix B, Figure 3-4).

The program read through the Excel files of the new word lists and found each target word in the lexical database. The phonetic code of each word was retrieved from the lexical database and was written into the computerised routine which returned all the phonological neighbours of the word. The program then read through all the phonological neighbours returned and checked their age-of-acquisition in the lexical database. Depending on the age selected, word neighbours were either known or unknown by children of that age and were placed in the respective neighbourhood groups (either effective or rejected). The total number of effective and rejected neighbours for each neighbourhood density metric was calculated for each target word and written into an Excel file. The total numbers of effective and rejected word neighbours were computed in Excel.

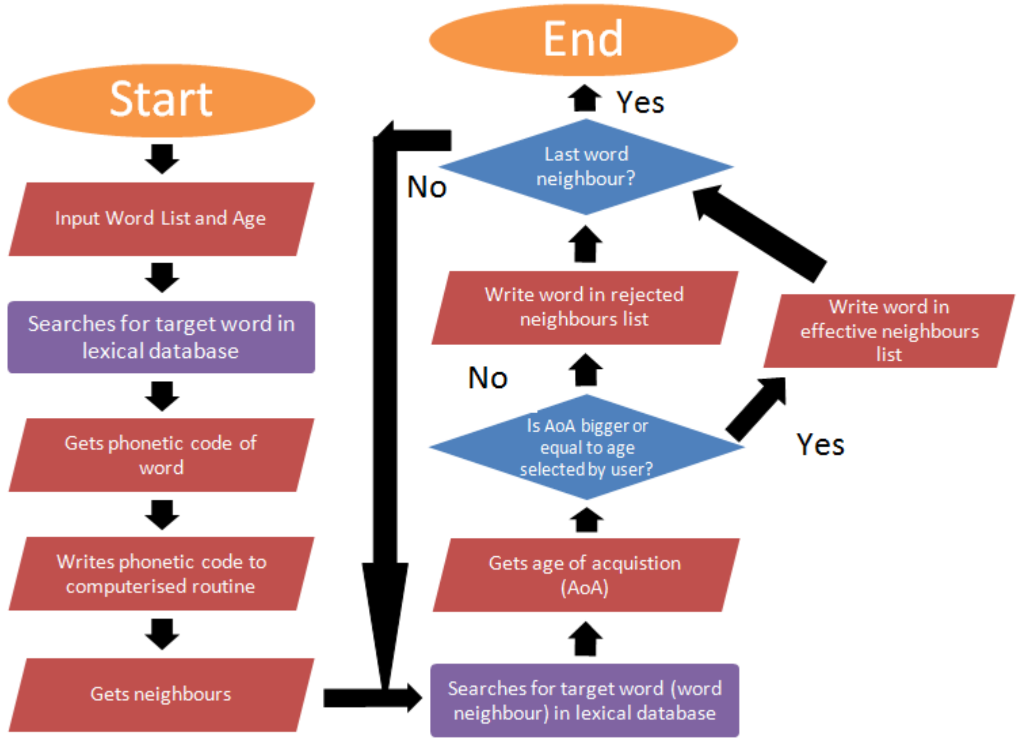

Figure 3-4. Process flow chart of Program 2. Note that procedures are defined by square boxes, Input/Output by parallelograms, and Start/End by oval boxes.

To make the analysis of second-order neighbours tractable, the word lists at 6 months intervals were used, starting from age 2, at which age children had a sufficient number of word neighbours to make the analysis meaningful; total range covered was from 2 years to 7 years and 6 months old. Excel files produced from individual children's data were grouped by age and then combined into one Excel file so that a combined file with all the words and their number of neighbours was available. After words without neighbours and any words which were duplicated were removed in Excel, mean splits were conducted on the word lists so that words were categorised as having a high number of first-order neighbours or a low number of first-order neighbours based on the summed number of OVC and Ph+/-1 metric word neighbours. Mean splits were conducted instead of median splits as the value of the neighbourhood density measure for each word clustered too closely around the median, therefore making it impossible to identify a precise cut-off point for a median split. Using the mean, words from the combined data were classified as either having high density first-order neighbours (above the mean) or low density first-order neighbours (below the mean).

In order to obtain second-order neighbours, a third purpose-written MATLAB program (Program 3) was run on the combined word lists to retrieve the strings of the effective first-order neighbours. The list of effective first-order neighbours was then processed by Program 2 again to get the number of effective and rejected second-order neighbours.

3.2.2.2.3 Program 3 (Appendix C)

Working in a similar way to Program 2, this program allowed the user to select the relevant age and it returned the string of the effective word neighbours at the requisite age.

The total number of neighbours for each metric (OVC, Ph+/-1) for the second-order neighbours for the combined data files was calculated so that mean splits could be conducted. Like first-order neighbours, second-order neighbours in the combined files were classified as either having high density second-order neighbours or low density second-order neighbours using mean splits. As a result, words from the combined data files from the different age groups can be categorised as: having high first- and second-order word neighbourhood density (HH), having high first-order word neighbourhood density but low second-order neighbourhood density (HL), having low first-order neighbourhood density but high second-order neighbourhood density (LH), or having low first- and second-order neighbourhood density (LL) (Table 3-1).

Table 3-1. *Category of word depending on their first- and second-order neighbourhood densities.*

First-Order Neighbours	**Second-Order Neighbours**	**Category**
High Density	High Density	HH
High Density	Low Density	HL
Low Density	High Density	LH
Low Density	Low Density	LL

3.3 Results

3.3.1 *Analysis One*

The relationship between the 59 age groups (those age groups with 23 transcripts or more) and the number of words known from the lexical database was assessed (range 9 months to 7 years and 6 months). From the graph it can be seen that there is a rapid increase in the number of words known between 1 and 3 years of age (Figure 3-5). This represents the vocabulary spurt. Spearman's Rank Order correlation coefficient indicated a strong positive correlation between the two variables, $r = 1.00$, $n = 59$, $p < .05$, with increased age associated with a larger number of words known from the lexical database.

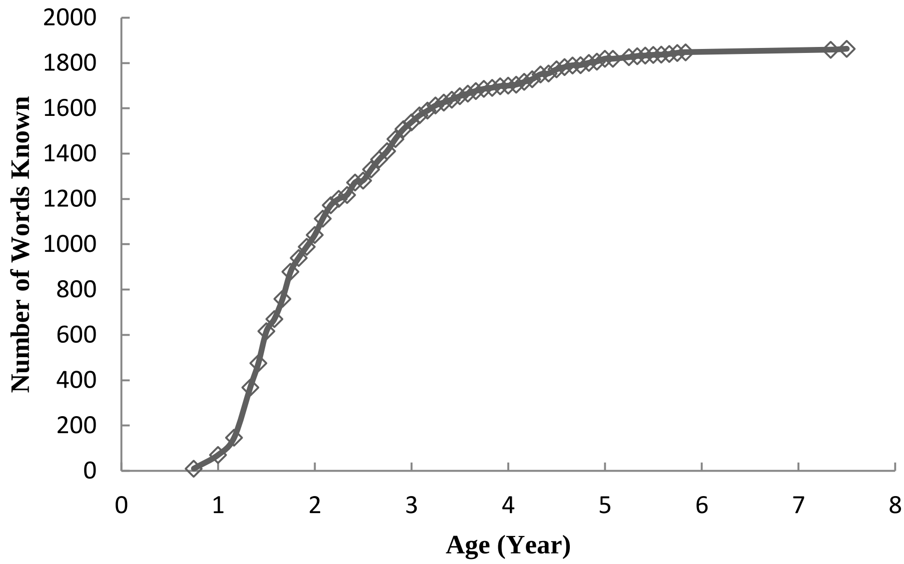

Figure 3-5. The number of words known from the lexical database of children at different ages.

3.3.2 ***Analysis Two***

Words known were divided into high and low neighbourhood density groups based on the number of effective first-order neighbours they have across the metrics (OVC and Ph +/-1). The age groups considered in Analysis One are not continuous (there are different gaps between each age group). As only children from age 2 onwards knew enough words for the neighbourhood density calculations to be meaningful, the final nine age groups considered here are 2 years, 2 years and 6 months, 3 years, 3 years and 6 months, 4 years, 4 years and 6 months, 5 years, 5 years and 6 months and 7 years and 6 months.

The number of words assigned to high and low density groups for both metrics combined over age are graphed in Figure 3-6. It can be seen that throughout development, the number of words with high density neighbourhoods was always less than the number of words with low density neighbourhoods. A Wilcoxon Signed Rank Test revealed a statistical difference between the two groups, $z = -2.666$, $p = .008$, with a large effect size ($r = .63$).

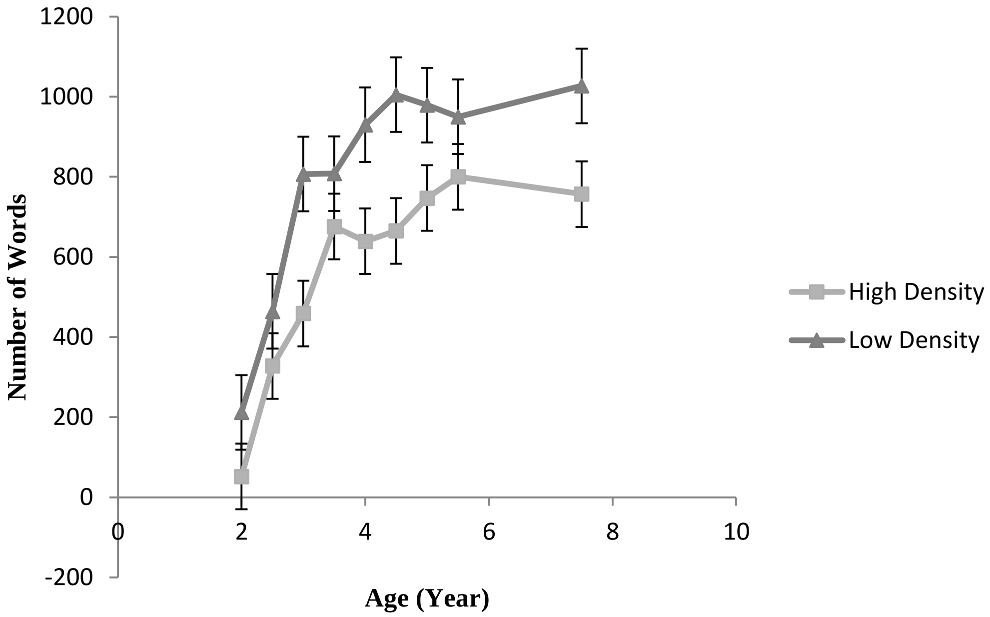

Figure 3-6. The number of words with high and low density first-order neighbours combined from both metrics (OVC and Ph +/-1). Error bars indicate standard errors.

3.3.3 *Analysis Three*

Based on the number of first- and second-order neighbours, words were grouped into four categories: HH, HL, LH and LL. The number of words in the four categories over development (the nine age groups) was then assessed (Figure 3-7).

From the graph it can be seen that the HH category has the lowest number of words, whereas the other three groups are quite similar and interact as age increases. A Friedman Test indicated a significant difference between the number of words in the four groups, χ^2 (3, *n* = 9) = 17.80, *p* <.001. Inspection of the median values showed an increase in words going from the HH group (*Mdn* = 247), to the LH group (*Mdn* = 379), to the HL group (*Mdn* = 420) and finally the LL group (*Mdn* = 446). *Post hoc* tests were conducted to see if there was a significant difference between the number of words in the HH group compared to the other three groups (HL, LH and LL). A Bonferroni adjusted alpha value of *p* = 0.0167 was used as multiple comparisons were made. Wilcoxon Signed Rank Tests revealed a statistically significant difference between the number of words in the HH group compared to the other three groups, with all of them having *z* = -2.666, *p* < .001, and a medium effect size (*r* = 0.44).

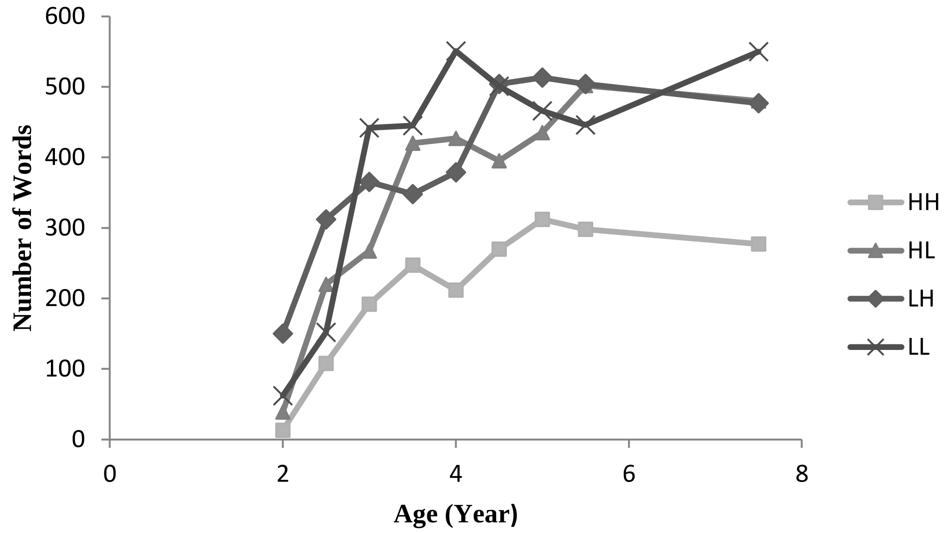

Figure 3-7. The build-up of the number of words with different first- and second-order neighbours (HH, HL, LH and LL) combined from both metrics (OVC and Ph +/-1) over age.

3.4 Discussion

From the results of the computational analysis it can be seen that there is a clear relationship between age and the number of words known for all word classes, where the general trend is that as age increases, the number of words known increases and first-, and second-order neighbourhood density also increased.

When the effects of first-order neighbours were looked at, there was a significant difference between the numbers of words with high and low density first-order neighbours, whereas there are always fewer words with high density neighbours compared to low density neighbours across age. This is illustrated in Figure 3-6. One reason for this could be because in early language development children are learning a variety of new words and those that include rare sounds (i.e.

have fewer neighbours) appear novel which is why they are learned quicker and thus there are a larger number of them (Hoover et al., 2010). Another reason could be that those words with low first-order neighbourhood density may be words that are needed for environmental communication, thus a higher number of these words were acquired compared to high first-order neighbourhood density words.

Similarly, when considering the combined effects of first- and second-order neighbourhoods, there was a significantly lower number of words in the HH group compared to the other three groups (HL, LH and LL). This could be explained in a similar way to first-order neighbours in that words in the HH group are either less novel so children have less interest in acquiring them compared to words from the other three groups or that these words are not as essential for communication in children.

Although clear trends were observed in the computational analyses, the neighbourhood density of the words from the transcripts was the only lexical factor controlled for. It is thus possible that there are other lexical factors that could have caused the effects demonstrated in Analyses Two and Three, such as word frequency. For example, words with HH neighbourhood density may happen to have the lowest word frequency, which is why there appears to be a lower number of HH words compared to the other three neighbourhood density groups. As there may be confounding factors for the results obtained, these need to be considered in order to provide a clearer representation of changes in the lexicon in childhood. In further studies, word frequency could be controlled for so that neighbourhood density effects could be better tested.

Nonetheless, the findings from these analyses are useful in helping to understand how lexical networks develop in the early years, in particular the number of words with different neighbourhood properties and how these interact. As there is a lower number of words in the HH group compared to the other word groups, it can be predicted that HH word processing should be different from the other word groups. The results from the computational analyses also favours the Global Activation Theory (Grainger & Jacobs, 1996). The reason for this is that as the HH word group has the lowest frequency, it appears that there may not actually be a lot of word competition in early lexical development as most of the words in the lexicon fall into sparse neighbourhood density groups (although things may change in later life). Instead it is possible that the small number of words in the HH group may actually help to facilitate acquisition of those words with sparse neighbourhood networks as they help the child with common phoneme combinations.

Although the results provide insight into the structure of lexical networks in children, there were limitations in the data used. One limitation was that the transcript files from the CHILDES database were mostly of data from 2 to 3 years old which meant that there were not enough data files for the other ages to produce a continuous estimate of the effect of words known and neighbourhood density over age. From the data it can be seen there is a gap in results between 5 years and 6 months to 7 years and 6 months, so it is hard to determine the changes in lexical networks above 5 years and 6 months. As children learn to read at around 5 years old, the changes in the lexical network may be different before and after this age, so it would be interesting to get more results for the older population to see if such differences do occur.

Another limitation with the data used is that neighbourhood density calculations were based on words that existed in the lexical database of De Cara and Goswami (2002), therefore the neighbourhood density statistics do not represent fully all the possible word neighbours a word can have, thus limiting the results to this database only. Furthermore, the strict criterion of removing all words with no neighbours from the analyses meant that there was a reduction in the number of items in the data. As words with no neighbours are hypothesised to not have connections with other words in the lexicon, they cannot be grouped into low neighbourhood density groups, thus these words were not examined and were removed to prevent extraneous variables from causing an effect. However, these words still exist within the lexicon and should be explored as well. Another research topic could therefore be exploring how words with no neighbours change over development, such as the number of words with no neighbours at different ages.

3.5 Conclusion

The computational analyses conducted were useful in obtaining more representative neighbourhood density statistics of known words in early development by adapting a detailed methodological approach using the CHILDES database. The results obtained illustrate the connections between words in the lexicon with respect to neighbourhood density and help to provide a basis for understanding lexical processing in children.

Using the data obtained from the computational analyses, materials can be designed to test the word production differences of the various word types in children to see if neighbourhood density classes affect performance. As discussed, it is possible that neighbourhood density has a facilitatory effect in early childhood in order to aid the rapid acquisition of vocabulary in the early years, therefore supporting the Global Activation Theory. It is predicted that if the Global Activation Theory is correct then those words with high first- and second-order neighbourhood density should be produced faster than those with low first- and second-order neighbourhood density, as those words with more neighbours contribute to create a summed activation level which helps to make articulatory units easier to retrieve. In the experimental study in the next chapter, this prediction is tested in a picture-naming experiment in children.

4 Chapter 4: Experimental Analysis on the Development of Lexical Networks

4.1 Experiment One

The computational analyses in Chapter 3 used a novel methodology to calculate word neighbourhood density. This built on current approaches by including calculation of second-order neighbours (neighbours of a word's immediate neighbours). The procedure was useful for identifying patterns in the acquisition of words in the lexicon over development. It showed, in particular, that the numbers of words with different first- and second-order neighbourhood density categories changes over development. This provides a basis for predicting how word neighbourhood density could have an effect on lexical processing. For example, using the computational programs developed in Chapter 3, it was found that the word 'cat' has two first-order word neighbours at age 2, and seven first-order word neighbours at age 5, even though the total possible number of word neighbours for 'cat' is 83. This demonstrates the importance of considering age-of-acquisition statistics when calculating word neighbourhood density.

There are limitations to the methods used in the current literature on looking at the effects of neighbourhood density on word processing. One is that the neighbourhood density statistics used were not appropriate for children, who have different lexicons from adults. Using the neighbourhood density statistics obtained in Chapter 3 this problem can be rectified, as the neighbourhood density statistics of words at given ages can be calculated.

The aim of the current experiment was to use the data obtained from the computational analyses to select stimuli to test how neighbourhood density affects children's word productions using a picture-naming task. A picture-naming task was chosen in order to prevent phonological and orthographical neighbourhood density influences being confounded as would happen if a task including reading was used instead (Coltheart, Davelaar, Jonasson, & Besner, 1977; Grainger, Muneaux, Farioli, & Ziegler, 2005; Ziegler et al., 2003). By selecting words children know at age 3 from the four neighbourhood density categories (HH, HL, LH and LL), it was possible to determine the impact of first- and second-order neighbourhood densities and whether these two factors interacted

From the trends observed in the computational analyses, it can be seen that there was a lower number of high first- and second-order neighbour (HH) words, suggesting that the Global Activation Theory is likely to be an appropriate theory for explaining neighbourhood density effects in lexical processing. It may be recalled that the Global Activation Theory predicts a facilitatory effect should arise as words with similar neighbouring units contribute together to produce a summed activation level that aids the retrieval of articulatory units of a target word.

One reason for favouring the Global Activation Theory is that early language development is a time when children are acquiring a large number of words as illustrated in Figure 3-5. Thus it would be more practical for words to facilitate the retrieval of other words rather than inhibit them as this would not only help children's speech development but also aid the acquisition of new words through the learning of word fragments (such as common phoneme combinations). Another reason is that since there is a lower number of HH words compared to the number in other neighbourhood density groups, there are comparatively few words that have a large number of links with other words. Therefore, if word competition was to occur it is unlikely that the competition would be strong enough to produce a large inhibitory effect, which implies that a facilitatory effect is more probable.

The results from the experiment should determine whether effects of neighbourhood density extend through to second-order neighbours in the lexicon. These findings would have implications for understanding child language development and determining the extent of extended connectivity in the lexicon.

In this experiment, words from different neighbourhood density categories based on the computational analyses were used in a picture-naming task to test the word production speeds of pre-school children (aged between 3 and 5). Children over age 3 were tested because the list of words used are words known from age 3 onwards. The age of 5 was selected as the maximum because this is the age when word acquisition levels off and neighbourhood density effects should become more stable and thus children are less likely to demonstrate neighbourhood density effects on lexical processing. A standardised test was performed to ensure the vocabulary abilities of the children in the sample were comparable: The British Picture Vocabulary Scale (BPVS) (Dunn, Whetton, & Dunn, 1982).

4.2 Method

4.2.1 *Participants*

Parents of 27 children from three different nurseries in London agreed to participate in the experiment (range of the children was from 2 years 3 months to 4 years 7 months). During the experiment, one child withdrew from the study and another one withdrew after completing the BPVS test. Also one child was under age 3 and was removed from the analyses. As a result, the data used in the analyses were from 24 children (10 males, 14 females). The mean age of the children was 3 years and 7 months (range 3 years 1 months to 4 years 7 months).

4.2.2 *Stimuli and Apparatus*

The BPVS (Dunn et al., 1982) was used to test the vocabulary of the participants. This standardised test ensured that none of the participants had any language problems, whilst allowing comparison with participants from other studies. The BPVS was chosen because the age range it tests is from 2 years and 1 month to 18 years and 1 month and thus is suitable for very young children. The BPVS can be conducted as a short form, or a long form, test. The long form test was used in this experiment to give more detailed information about each child.

The words used in the picture-naming task were obtained from those selected in the computational analysis. Words that children had already acquired at age 3 (according to the word list produced in Program 1, Appendix A, Figure 3-3) were used for this experiment.

The list of words that children knew at the age of 3 was run through Program 2 (Appendix B, Figure 3-4) so that the words could be ordered by the number of combined neighbours from the metrics (OVC, Ph+/-1). Words with no neighbours were removed from the list and the mean number of neighbours was calculated (*M* = 4.40). The remaining words were split into high and low first-order neighbourhood density groups based on whether the number of neighbours they had was above or below the mean number of neighbours.

Mean splits were conducted as the value of neighbourhood density for each word clustered too much for median splits to be effective; it was not possible to identify a precise cut-off point. The words were run through Program 3 (Appendix C) in order to retrieve the strings of the second-order neighbours. The strings returned were then run through Program 2 (Appendix B, Figure 3-4) to obtain the number of neighbours for the different metrics. The total number of neighbours across the metrics for second-order neighbour words was calculated and a mean split was made on the lists from the two groups (mean for the high first-order neighbourhood density group = 63.50, mean for the low first-order neighbourhood density group = 12.54).

For each group, words with the number of neighbours above the mean were allocated into the ‘high density of second-order neighbour’ group and words with the number of neighbours below the mean was allocated in the ‘low density of second-order neighbour’ group. The words were then split into designated groups as shown in the matrix that follows (Table 4-1):

Table 4-1. *Category of word depending on their first- and second-order neighbourhood densities.*

First-Order Neighbours	**Second-Order Neighbours**	**Category**	***N***
High Density	High Density	HH	20
High Density	Low Density	HL	20
Low Density	High Density	LH	20
Low Density	Low Density	LL	20

Words from the word lists of the four categories were assessed to see if they had corresponding pictures in the Microsoft clip art library. Standardised pictures from the International Picture-Naming Project (Centre for Research in Language of the University of California, San Diego) were also checked against the word list. There were not enough word-picture matches in the standardised picture database so the former was used. At the end of the selection process, 20 words which could be represented by Microsoft clip art pictures as clear and simple images were selected from each category, giving a total of 80 words (Appendix D). As a result of the selection criteria, the words obtained were all content words and seven of these words were BPVS items (see Appendix D). All the chosen pictures were changed into greyscale.

Due to the constraints imposed by the selection of the stimuli, the number of words in each of the four categories (HH, HL, LH and LL) was limited. First, words had to be known by children at age 3 and have first- and second-order neighbours so that they could be categorised into the four groups. A sufficient number of words was needed in each category so that an equal number of stimuli could be obtained and used in the test. Second, words needed to have corresponding clear Microsoft clip art images so that they could be used in the picture-naming test. This meant only a small selection of words were available for testing. It is thus important to look at the words that were selected and to analyse them statistically in order to ensure that other factors have not caused an effect which might account for the picture-naming task results.

One of the factors checked was word frequency, as studies have shown that word frequency can interact with neighbourhood density (Harley & Bown, 1998; Metsala, 1997a; Spieler & Balota, 2000). To estimate word frequency, a MATLAB program (Program 4) was written to obtain the spoken word frequencies of the words selected. The word frequencies correspond to the CELEX measure for spoken frequency of lemmas, which is the occurrence of the target word per million words within a 17.9 million spoken word corpus (Baayen et al., 1995).

Program 4 (Appendix E) ran through the word list and located each word's entry in the lexical database. The spoken word frequency of each word was obtained from the database and written into an Excel file.

From the descriptive statistics of the word frequency data (Table 4-2), it appears that the mean word frequency and standard deviation of the word category HL is higher than the same statistics of the other categories (*M* = 88.80, *SD* = 182.656). This suggested that some of the words in this category were outliers (exceeded 1.5 times the interquartile range). These were identified and removed from the sample; thus the two words 'book' and 'hand' were removed from the HL category, leaving *N* = 18 for the HL group in the final data analyses. A one-way between-groups analysis of variance was conducted to see if there was a significant difference between the word frequencies of the words from the four word categories after the outliers were removed. The test showed that there was no significant difference in word frequencies between the four word category groups: $F(3, 74) = 0.671$, $p = 0.573$. It is thus safe to assume that word frequency did not have an effect on the results of the study.

Table 4-2. *Descriptive statistics on word frequency for the words chosen for the experiment.*

Word Category	***N***	**Mean**	**Standard Deviation**
HH	20	57.65	65.884
HL	20*	88.80	182.656
LH	20	45.10	90.574
LL	20	32.50	29.121

(* *N* = 18 (*M* = 35.83, *SD* = 35.756) after the two outliers were removed).

4.2.3 ***Procedure***

Participants were tested on the BPVS long form first (Dunn et al., 1982). For each trial in the test, the examiner said a word and the participant was required to point to one of four pictures on the BPVS plates that they thought represented the word (Figure 4-1). A minimum of four training plates was used to ensure participants could produce the required pointing behaviour. In some cases, more training plates were required in order to establish this. In these cases, further training plates from the BPVS were administered until the child could accurately point to the correct answer on four consecutive training plates.

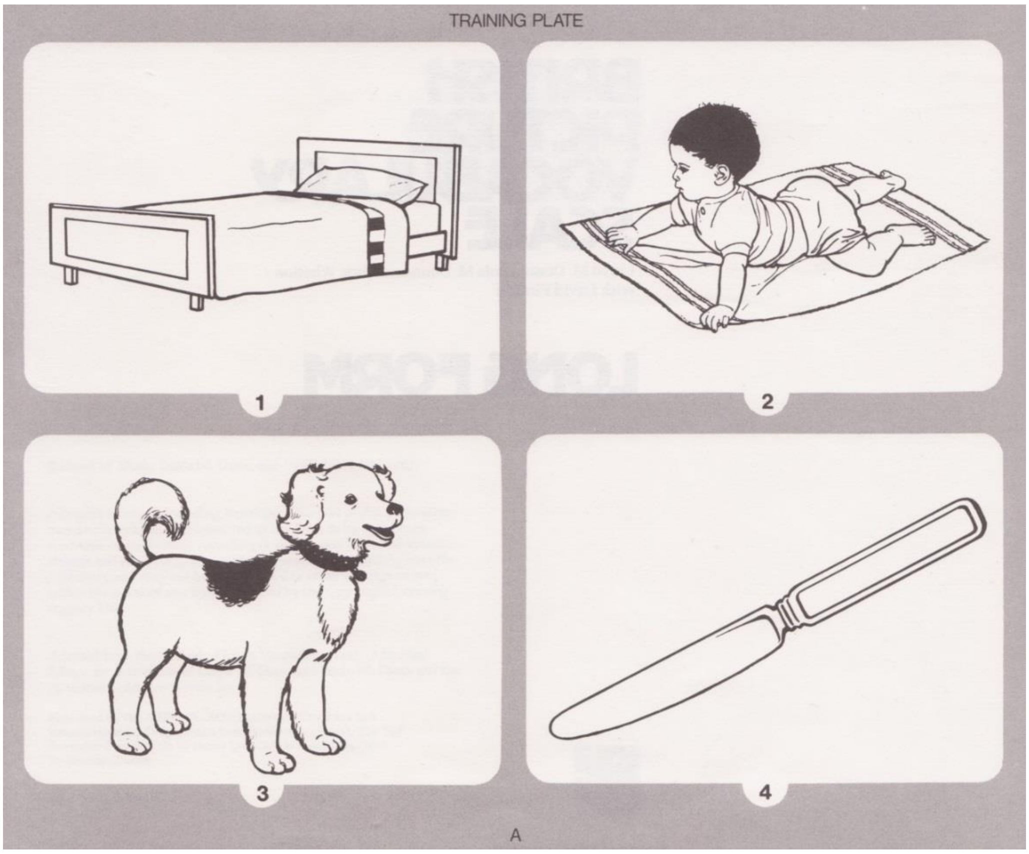

Figure 4-1. An example of a training plate used in BPVS.

After the training trials, the BPVS test trials were conducted. The plates used for the test trials were appropriate for the participant's age. Test trials continued until a basal item and a ceiling item were established where the basal item is defined as the most difficult correctly answered item with seven consecutive correct answers preceding, and the ceiling item is defined as the lowest item after the basal item with six incorrect responses out of eight consecutive items. Participants' raw scores from the test were calculated by deducting the number of errors from the ceiling item. Raw scores were then converted into standardised scores using the tables in the BPVS manual.

The picture-naming task was conducted after the BPVS test. Each picture was displayed as one PowerPoint slide with the picture centred and the length of the longest side of the picture set at 10.16cm. The order of the pictures from the different categories was randomised and counterbalanced. A ‘click’ noise accompanied each word as it was presented on the screen. This and the response were recorded and they were used to measure participants’ reaction times (times from the start of the ‘click’ to onset of word production). Hesitations and incomplete syllable repetitions were ignored so that reaction time only measured the time between the start of the ‘click’ and the start of the production of the whole word (in milliseconds). Participants’ speech was recorded using the Audacity software package.

To check the validity of PowerPoint as a program to use for a picture-naming experiment, the Vegas Pro 13 (n.d.) program was used to estimate the elapse time between the slide onset (when the picture is presented) to the click onset (the sound of the click). For the 80 test trials, the mean elapsed time between slide onset and click onset was 0.22ms, with a standard deviation of 0.11. The coefficient of variation (CV = SD / M) was 0.509, indicating a relatively low variation. Due to the unreliability of the video format which is based upon hardware usage at the time of recording, and the limiting factor of the number of frames per second (120) for the video, the actual results may differ slightly. The software used to read the video in frames per millisecond may also have slight variance in timings, as some of the slides had small estimates. The video and the slideshow itself would have different timings based upon hardware and hardware usage at the time, and as such it would be difficult to replicate the exact timings of this procedure.

Participants were first shown all the pictures (in a randomised order) using PowerPoint and were asked to say what the pictures represented (pre-test recognition trials). Help was given to participants who found it difficult to name a picture. This ensured that all the participants knew what the pictures represented and were able to produce the words correctly. After checking that the participants could say what the pictures represented correctly, three practice trials were presented. Practice trials were used to make sure participants knew what was required in the test. For all the trials (practice and test), participants were shown a fixation cross in the middle of a PowerPoint slide for two seconds before a picture and a click noise was produced. Participants were asked to name the pictures as quickly as possible. The experimenter waited for the participant's response before pressing a key on the laptop which resulted in the next trial being presented. The whole duration of the BPVS and picture-naming task lasted around 30 minutes for each child.

4.3 Results

For the picture-naming task, incorrect trials or trials without responses were omitted from the analysis. The reaction time between each 'click' and the spoken response was calculated for each word (in milliseconds).

The mean standardised score on the BPVS for the participants was 102.63 (range 84 to 126). None of the participants differed significantly from the sample (i.e. exceeded 1.5 times the interquartile range) so all the participants were included in the analysis. The picture-naming data of each participant were examined in SPSS in order to remove any reaction time outliers. Data points were identified as outliers if they were greater than 1.5 times the interquartile range to the nearest quartile. After removing the outliers, five participants (21% of the sample) could not name more than 50% of the pictures. The analyses on the data therefore excludes these participants, as accuracy of performance was close to chance.

In order to prevent confounding effects between the BPVS and picture-naming task, words in the picture-naming task which appear in the BPVS task were removed from the analysis. This resulted in 72 words for the final analysis (HH = 19, HL = 16, LH = 19, LL = 18), analysed across 19 participants.

Statistical tests were conducted to explore the impact of first- and second-order neighbourhood density effects on picture-naming response times to see whether a facilitatory neighbourhood density effect exists as predicted by the Global Activation Theory. First-order neighbourhood density was grouped into those either having high or low first-order neighbourhood density. Second-order neighbourhood density was grouped into four classes (HH, HL, LH and LL).

Clark (1973) argued that language effects should be treated as random factors because psychologists do not want to limit the statistical effects obtained only on the selected stimuli but to be able to generalize them to all words of that category. In order that the effects for first- and second-order neighbourhoods can be generalized to other stimuli, phone string categories should be treated as a random factor rather than a fixed factor. However, as the two factors being investigated determined the types of words used for testing, it was not possible to conduct a mixed-effects model with these factors assigned as random factors. Also as second-order neighbourhood density was dependent on first-order neighbourhood density, the factors had to be put into the model separately; therefore separate tests were conducted for first- and second-order neighbourhood density where the respective factors were entered as fixed factors.

4.3.1 *First-Order Neighbourhood Density Effects*

An independent-samples *t*-test was conducted that compared the effects of words with high and low first-order neighbourhood density on picture-naming response times. The independent variable was the first-order neighbourhood density of each word (high, low) and the dependent variable was the reaction time of the participant for each word (ms). There was no significant difference in the picture-naming response times of words for high (M = 1.551, SD = .729, N = 372) and low first-order neighbourhood density (M = 1.591, SD = .779, N = 413); t (783) = .739, p = .460. This indicated that first-order neighbourhood density of the words did not affect picture-naming response times.

4.3.2 *Second-Order Neighbourhood Density Effects*

A one-way between-groups analysis of variance was conducted to explore the impact of second-order neighbourhood density of words on picture-naming response times. The independent variable was the second-order neighbourhood density of each word (HH, HL, LH, and LL) and the dependent variable was the reaction time of the participant for each word (ms). There was no significant difference in picture-naming response times for the four second-order neighbourhood density categories, F (3, 784) = 1.075, p = .359. This showed that second-order neighbourhood density of the words did not affect picture-naming response times.

4.4 Discussion

From the analyses of the results it can be seen that neither first-order nor second-order neighbourhood density produced any effect on the picture-naming response times of pre-school children. The results thus go against the prediction that first- and second-order neighbourhood density should have a facilitatory effect on word production, as proposed by the Global Activation Theory. As no neighbourhood density effect is present, it could mean that connectionist ideas about the mass connectivity between words in the lexicon can possibly be rejected for children, as the links between words in the case of neighbourhood density do affect lexical processing. It may thus be possible that words are stored as separate units, similar to the way described in search models of language processing and that no interaction between units occurs.

Although the findings from the experimental study go against the predictions made by connectionist models, there are a number of methodological problems with the experiment that could have affected the results. First, the current experiment may have been too long, as with the BPVS and picture-naming task included, the assessment lasted approximately 30 minutes for each participant (15 minutes for each task). Second, the tests used were quite repetitive, as participants had to point to a series of plates for the BPVS which consisted of between 8 and around 50 plates, depending on participants' performance. Furthermore, the picture-naming task that was presented after the BPVS and involved 80 pictures which participants needed to name pre-trial and during the trials. For children of the ages tested, the trials in the experiment may not have been interesting enough and fatigue effects could have occurred. This could be a reason why 21% of the participants did not name more than 50% of the items, even though pre-test recognition trials were performed to check that the children knew the names of the pictures presented.

Therefore, for further studies it may be necessary to consider other ways of testing, with particular reference to reducing fatigue effects and producing more accurate results. For example, instead of picture-naming, a word repetition test could be used instead as this should decrease the number of pre-test trials required (Adams & Gathercole, 1995). Also a word repetition task should avoid any problems of using reaction time as a dependent variable. Reaction time is a highly sensitive measure and any variation could cause effects to be lost. For the participants tested in this experiment, the reaction time measure appeared to lead to high variability, as indicated by the participants whose data points were identified as outliers, and who had to be removed from the analysis; they did not name more than 50% of the items.

One other reason that could have caused the low accuracy in participants' responses could have been because children were told to respond as quickly as possible to the pictures when presented. This instruction could have caused a trade-off between accuracy and reaction time.

Moreover the words used in the experiment were restricted to monosyllabic words that existed within the lexical database (De Cara & Goswami, 2002), thus not all possible known word neighbours were considered in the test and this could have had effects on the neighbourhood density of the words. It is therefore important to write a program that returned all possible neighbours of a word (both monosyllabic and multisyllabic) before deciding whether the word was acquired at the selected age or not.

Furthermore, although word frequency was controlled using data from the CELEX Lexical Database (Baayen et al., 1995). As the information from CELEX is based on adult data, the same methodological problems of using adult data to determine word neighbourhood density is applied here, meaning that the word frequency statistics of the words are not representative for children. In order to completely account for word frequency as another lexical factor that can affect word processing, word frequency would also need to be calculated based on age, as is done in Chapter 3 for neighbourhood density. This way the effects of word frequency can be controlled for and it may be possible that a neighbourhood density effect can then be observed.

Another methodological problem with the study that could have caused the non-significant results is the use of the picture-naming task to determine lexical retrieval. Cognitive models of naming have argued that the three stages that occur in picture-naming are object identification, name activation, and response generation (Glaser, 1992; Johnson, Paivio, & Clark, 1996; Paivio, Clark, Digdon, & Bons, 1989). The object identification and name activation processes are nonverbal and involve covert naming. In contrast, the response generation is overt naming. Thus it is possible that a child can identify a picture, but lack the auditory-motor ability to produce the word without the aid of the experimenter. This could explain why a child could reproduce the names of pictures they did not know in the pre-test recognition trials with the help of the experimenter (repeating what the experimenter says the word is), but not in the test trials where the experimenter could not help.

Despite the arguments made in the literature, Herbert, Hickin, Howard, Osborne, and Best (2008) have shown that picture-naming tasks provide a valid assessment of lexical retrieval, as a significant correlation was found between picture-naming scores and lexical retrieval parameters in conversation. However, this experiment was conducted with adults with aphasia so the results may not be generalizable to a child population. Nonetheless, it appears that the task chosen to test children's lexical processing of words with different neighbourhood density may need to be reconsidered in the following experiments. It should be further noted that although the validity of PowerPoint was checked and a relatively low variation was found between slide onset and click onset, a program which is designed for computerised experiment design and data collection such as E-Prime ('Psychology Software Tools, Inc. [E-Prime 2.0]', 2012) and Cogent ('Cogent', n.d.) would have been more appropriate for the purpose of this study.

Based on the methodological problems with the current experiment, the results obtained are not conclusive and cannot be used to reject connectionist modellers' approaches. The next experiments therefore aimed to take into account the issues faced here so that new improved experimental studies could be conducted and neighbourhood density effects could be further investigated.

5 Chapter 5: Neighbourhood Density Changes in Development: How a string of phones shifts from being treated as a non-word to a word during language acquisition

5.1 Introduction

Research has suggested that the properties of the same words in children's and adult's lexicons differ depending on what neighbouring words are known by the two age groups (Charles-Luce & Luce, 1990, 1995; Storkel & Morisette, 2002; Storkel, 2004). In particular, studies have reported that younger children have fewer word neighbours than older children and adults (Charles-Luce & Luce, 1990, 1995). Since different words exist in children's lexicons because of their age, words should vary in their first- and second-order neighbourhood density properties over development. The computational analyses conducted in Chapter 3 confirmed this. They showed how the number of first- and second-order neighbours shifted across childhood, illustrating how an individual's mental lexicon is reorganised over development as more words are acquired.

It was found that the number of words with high and low first- and second-order neighbours changed with age, in particular, there was a significantly lower number of words in the HH (high first- and high second-order word neighbours) group compared to the other word groups which implies that children learn fewer of these words in development compared to other word groups. It appears from the computational analysis in Chapter 3 that the number of words with HH, HL, LH and LL neighbourhood density properties increases rapidly during the vocabulary spurt but then levels off around age 5 as fewer words are acquired into the lexicon. In particular, at age 2, the number of LH words was the greatest, the maximum category changed to LL words for ages 3 and 4, and then back to LH words at age 5, before finally reverting to LL words from 7 onwards.

The neighbourhood statistics for children at age 3 were used in the experiment in Chapter 4 to determine whether words with different neighbourhood properties affected word processing and production. The results of the experiment showed no significant difference in the picture naming response times of words with different neighbourhood densities, which rejected the hypothesis that neighbourhood density properties affects word production. However, it is possible that no significant differences were found because of the methodological decisions in the experiment that may have generated material that placed high demand on the participants in the experiment and also the limitations of the computational analysis in Chapter 3 in obtaining words for testing.

Hence, whilst the findings from the computational analyses and the first experiment are useful in understanding how the mental lexicon develops, there are limitations in the experiment that need to be addressed. First, the words used in both the computational analyses and the experiment were monosyllabic because the statistics were restricted to words from the lexical database of De Cara and Goswami (2002). This may therefore not provide a complete picture of how the lexicon develops. Thus, a new computational analysis which considers multisyllabic words in the neighbourhood statistic calculations needs to be developed to provide more representative stimuli for testing. Second, the picture-naming task used in Chapter 4 that employed these stimuli may not have been appropriate for the age group tested due to the high number of items and length of the test. As a result of this, another test that makes less demand and is shorter in duration may provide more representative results. That test will use the improved stimuli generated in this chapter.

Furthermore, a point that was not considered in the first computational analyses and the first experiment was the acquisition of new words in the lexicon over development, essentially indicating how a string of phones changes from being a non-word to a word. At birth, before words are acquired, all phone strings are non-words. They only become words after they have been learned as described in the literature review in Chapter 2. When a phone string changes from a non-word to a word, there are dynamic changes in the lexicon and to word neighbourhood densities as the now-learned word picks up neighbours and serves as a neighbour to related words. Consequently, the way words are processed, recognised and produced differs depending on whether the phone string is a word or a non-word for the individual and all these factors are age-dependent. Test materials need to be devised that allow these dynamic changes to be determined. Therefore, in this chapter, new computational analyses were conducted to establish word and non-word first- and second-order neighbourhood density statistics for two ages. New stimuli were selected for testing children based on these analyses in subsequent experiments where the effects of age and phone string type on production accuracy were assessed.

It has been found that children as young as 19 months are already affected by phonotactic regularities. For example, Friedrich and Friederici (2005) looked at event-related brain potentials when participants were presented with pictures of known objects. It was found that 19 month old children, like adults, have an N400 component (a signature that indicated semantic processing) when pseudo-word (non-words which would follow English phonotactic constraints) were presented. The N400 component was also present when incongruous words (words that did not match the picture) were shown. However, the N400 was not elicited when non-words (phonotactically illegal non-words) were presented. This shows that children as young as 19 months can already treat phonotactically legal pseudo-words as potential words but not phonotactically illegal non-words.

Consequently, this study establishes differences between non-words and pseudo-words. This thesis is interested in the way that words not yet known are acquired and enter the lexicon. For the subsequent experiments, there are three types of phone strings for sets of words at given ages: words known (acquired by the child at that age), words not yet known by children at that age (NK words) and pseudo-words (non-words that follow phonotactic constraints which are never acquired into the lexicon). NK words are different to pseudo-words because NK words are words that exists in the English dictionary. NK words are perceived in a similar way to pseudo-words by a child because both are not acquired in their lexicon so they are arguably seen as non-words by the child. Friedrich and Friederici's (2005) study would predict that NK words and pseudo-words would be processed equivalently semantically.

5.1.1 *Factor of Age*

In the experiment in Chapter 4, the stimuli used were based on words children know at age 3 as supplied from the computational analyses reported in

Chapter 3. Similarly, in the new computational analyses, first-and second-order neighbourhood densities of words known at age 3 were calculated and words were grouped into high and low first- and second-order neighbourhood densities for testing.

A further list of words not known until age 5 was obtained so that the word-NK word factor could be examined in experiments 2 and 3 and its effects established. Age 5 was chosen because vocabulary acquisition levels off and fewer new words are acquired after this age (Figure 3-5). Having the neighbourhood density statistics of words known at age 3 and age 5 available, it is possible to test how neighbourhoods are reorganised as children learn new words. For children under age 5, the list of additional words acquired between age 3 and age 5 would be NK words as they have not yet acquired them into the lexicon. When acquired, these items enter the lexicon and establish neighbour connections with other words. Identification of words with these properties is needed to test the ideas from the Generative Acquisition Hypothesis Processing Shift Model discussed in Chapter 2.

As well as calculating first- and second-order neighbourhood densities of words known at age 3 and age 5, the list of pseudo-words at age 3 and age 5 was also computed so that word-pseudo-word differences could be examined. The list of pseudo-words should not be words at any age, whereas words not known until age 5 would be NK words for children under 5. Therefore it is possible to compare pseudo-words with words children aged 3 do not know (NK words) and compare each of these sets of stimuli with words known by all children (words known at age 3).

5.1.2 *The Present Study*

The new computational analyses established first- and second-order neighbourhood density statistics for words known at age 3, words not known until age 5 (based on words known at age 5) and pseudo-words (at age 3 and age 5). The Generative Acquisition Hypothesis Processing Shift Model proposed in Chapter 2 as an extension to Vitevitch and Luce's (1999) model, predicts how words and non-words are affected by neighbourhood density in different ways and helps to identify the processing strategies (top-down or bottom-up) that are used when children of different ages produce language. At the general level, by examining the processing shifts that occur in individuals using stimuli of different types, it is possible to further understand the development of lexical networks and the way the lexicon is reorganised throughout development.

For this study, computational analyses were performed using databases that provided age-of-acquisition and neighbourhood density statistics. The databases included multisyllabic words, so that changes in first- and second-order neighbourhood densities over age could be established for them. Similar to the first computational analyses, first- and second-order neighbourhood density were identified as high or low for both words and pseudo-words. Specifically these properties were computed based on word age-of-acquisition data at the two selected ages (ages 3 and 5 years).

5.2 Computational Analyses Two

In order to include multisyllabic words into the neighbourhood density calculations, a new program was written. The aim was to obtain statistics on the new stimulus sets described (extended to pseudo-words, NK words for 3-year-olds and multisyllabic materials) so that new tests of children's word production could be conducted.

5.3 Method

5.3.1 *Stimulus Selection and Procedure*

The computational analyses were intended to select words known at ages 3 and 5, and pseudo-words with high and low first- and second-order neighbourhood density, controlling for word frequency effects. The final stimuli obtained from the computational analysis consisted of 48 words and 24 pseudo-words grouped into 12 categories based on their neighbourhood density properties. For each of the word groups, the words were split into groups known by 3- and 5-year old children based on age-of-acquisition data from the child language data exchange system (CHILDES) database (MacWhinney, 2000). The ages of the children that participated are given in months. As American children's data were the most numerous in CHILDES, their conversation transcripts were used. Transcript files of children aged 3 and 5 were selected. The median number of transcript files for the two age groups in the database was 23 hence 23 transcript files were chosen each from the transcript files of children aged 3 and 5.

Using CLAN, an analysis package for CHILDES, children's transcript files were analysed to select words spoken by the children. The speech data from each individual child's transcript file were saved into an Excel file, and each word obtained was either tagged as a word known at both ages (known at age 3 and 5), or only known at age 5 (NK words for 3 year olds). There were 6,131 words known by both ages, this selection is termed the age 3 list. There were 2,575 extra words not known until age 5 (words that only children age 5 and above know) which is referred to as the age 5 list.

In order to obtain the neighbourhood density properties of the words from the two word lists (ages 3 and 5 years), a computer program ‘neighbours’ was written with the help of Professor Mark Huckvale (University College London). The program returned the number of valid neighbours a target English word has through single phoneme deletion, substitution or insertion. The program used a British English dictionary called BEEP which includes the phonemic transcriptions of over 250,000 English words in British English pronunciations. When a word was entered, the pronunciation of the word was found by the program (conversion from orthographic to phonemic form).

To obtain all possible neighbours of the target word, each vowel and consonant of the word was processed first through deletion and then by substitution of other vowels when the phoneme was a vowel and other consonants when the phoneme was a consonant. Vowel to consonant and consonant to vowel substitutions were not made to avoid changing the number of syllables in the string. Therefore, this procedure ensured any first- and second-order neighbours came from a string that had the same number of syllables as the target string. Preventing syllable change removed a potential extraneous variable that could have led to processing changes. Finally, for all phone positions, all possible vowels and consonants were inserted in sequence. Each result from the vowel and consonant deletion, substitution and insertion was looked up in the dictionary to see whether it matched any real words and the phone strings were converted to orthographic form. As the dictionary did not contain age-of-acquisition data, it was modified before phone strings were assessed for word/non-word status by selecting just those words known at the particular ages being assessed (3 or 5 years). Thus when words that children know at age 3 were examined, only the 6,131 words from CHILDES were included in the dictionary. When words that children know after age 5 were examined, the extra 2,575 words that children know by that age were included in the dictionary (making 8,706 words altogether).

The modified dictionaries that included only the words children knew at the selected ages were used to calculate the number of first- and second-order neighbours of the words. First-order neighbours were calculated directly as described in Chapter 2. The number of second-order neighbours was obtained by generating the first-order neighbours and then examining each of those that were words to see what word neighbours they had. These calculations were conducted for all word lists. The procedure is summarized in Figure 5-1. Eight groups of words were created by combining words with high and low numbers of first- and second-order neighbours of the words in the word list (Table 5-1). A similar procedure was conducted to produce an equivalent eight groups of pseudo-words.

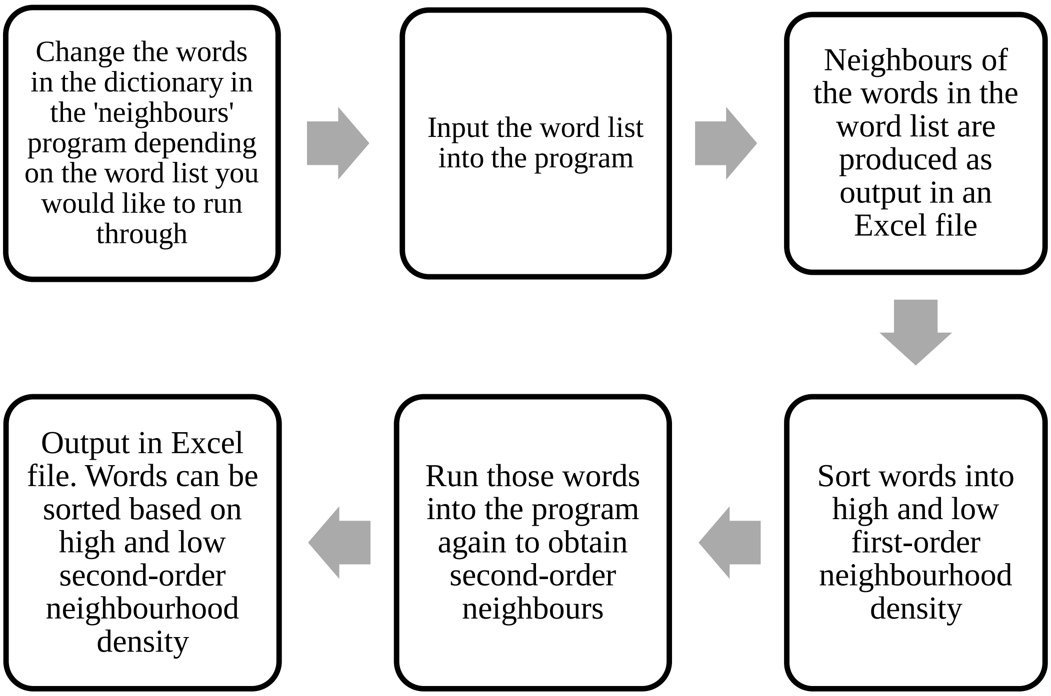

Figure 5-1. Summary of the procedure for obtaining neighbourhood properties of words.

Table 5-1. *Categories of words and non-words based on their first- and second-order neighbourhood densities.*

		Words			
		Based on Age 3		***Based on Age 5***	
		First Neighbour			
		High	*Low*	*High*	*Low*
Second Neighbour	*Low*	3HL	3LL	5HL	5LL
	High	3HH	3LH	5HH	5LH
		Pseudo-word			
		Based on Age 3		***Based on Age 5***	
		First Neighbour			
		High	*Low*	*High*	*Low*
Second Neighbour	*Low*	NonHL3	NonLL3	NonHL5	NonLL5
	High	NonHH3	NonLH3	NonHH5	NonLH5

Words were designated as having a high number of first-order neighbours if the number of neighbours was above the 95th percentile for all the words in the set for the corresponding age group. Similarly, words were designated as having a low number of first-order neighbours if the number of neighbours was below the 5th percentile. For second-order neighbours, words were split at the median number of neighbours, so that those above the median were considered as having a high number of second-order neighbours and those below the median were considered as having a low number of second-order neighbours. The reason why high and low neighbourhood definitions were different for first- and second-order neighbourhood density was because there were not enough second-order neighbours in the computed list that could be matched between groups for the selection criteria (words were controlled for spoken word frequency and the number of syllables).

All the words and pseudo-words used in the experiment were matched for the number of syllables. Spoken word frequency statistics were obtained for words and summed spoken frequency of phonological neighbour statistics were obtained for pseudo-words. The word groups were compared for spoken word frequency based on the British National Corpus (Leech, Rayson, & Wilson, 2001). The frequency of the words ranged between 10 and 211 per million words. Words in plural forms were excluded from the list to ensure that this did not affect the experimental results.

Although neighbourhood density was defined differently for first- and second-order neighbours, the same definitions are used across all three sets of materials (words known at age 3, words not known until age 5 (based on what words are known at age 5) and pseudo-words at age 3 and age 5). Also, independent samples *t*-tests were run between the high and low neighbourhood density phone strings selected to ensure that the differences between first-order and second-order neighbourhood groups were significant and that they belonged in the groups with their designated neighbourhood density properties. Details are given in the results section.

Pseudo-word stimuli were selected in a similar way. Using the ARC non-word database (Rastle et al., 2002), pseudohomophones which had orthographically permissible onsets and rimes, and were legal bigrams, were selected. This ensured real word phonotactic constraints were maintained. Out of the 4,631 pseudo-words that met the criteria, pseudo-words were removed if their phonetic transcripts matched with words in the British English dictionary BEEP or sounded similar to real words when pronounced in the online text to speech program Acapela (‘Acapela Text to Speech Demo’, n.d.). Pseudo-words were played to English speaking adults and were deemed similar if they considered that the pseudo-word could be mistaken for a real word.

The pseudo-words were assessed for the number of phonological neighbours and neighbourhood frequency was calculated so that they could be matched to the neighbourhood density and word frequency properties of the words for the 3 and 5 year-old age groups. The chosen list of pseudo-words was run through the ‘neighbours’ program using words that children know at ages 3 and 5 (depending which dictionary was selected) so that the first- and second-order neighbourhood properties could be obtained and the pseudo-words could be sorted into the corresponding groups of phone string stimuli (Table 5-1). The procedure for doing this was identical to how first- and second-order neighbourhood densities were calculated for words. That is, the lists of pseudo-words were entered into the 'neighbours' program with either the age 3 or age 5 dictionary. Thus, the neighbourhood density statistics obtained were relevant to the age group selected.

At the end after matching the phone strings based on the selection criteria, there were only 6 phone strings in each of the 12 categories (Appendix F). It is possible that less stringent selection criteria, such as allowing a wider variation in word frequency when matching phone strings would have yielded more stimuli. The analysis of the phone strings obtained from the computations was based on the three main groups of stimuli: words known at age 3 (known by both ages 3 and 5), words not known until age 5 and known by children over age 5 (NK words for children at age 3) and pseudo-word (at age 3 and age 5).

5.4 Results

5.4.1 ***Statistical tests that check whether the phone strings have their designated properties***

5.4.1.1 **First-Order Neighbourhood Density**

Independent samples *t*-tests were run to check the first-order neighbourhood density statistics of the words and non-words to check that those in low neighbourhood density groups were significantly different from those in the high neighbourhood density groups. This is important as it is a way of ensuring that the words and non-words are appropriate for their designated category so any experimental differences found in word production are a result of the specific properties of the words in the group.

An independent samples *t*-test was conducted to compare the number of first-order neighbours for words known at age 3 for the low and high first-order neighbourhood density word groups. There was a significant difference between the low and high first-order neighbourhood density word groups, $t(22) = 34.541$, $p < .001$.

A similar independent samples *t*-test was conducted on words not known until age 5 (NK words for children under age 5). Levene's test was significant, $F = 13.058$, $p = .002$, so a t statistic not assuming homogeneity of variance was computed. The results of the *t*-test revealed a significant difference between the low and high first-order neighbourhood density word groups, $t(11) = 13.428$, $p < .001$ (equal variances not assumed).

In addition, an independent samples *t*-test was conducted to compare the number of first-order neighbours on the set of pseudo-word for the low and high first-order neighbourhood density groups. As Levene's test was significant, $F = 5.571$, $p = .023$, a t statistic not assuming homogeneity of variance was computed. There was a significant difference between the low and high first-order neighbourhood density word groups, $t(31) = 9.852$, $p < .001$ (equal variances not assumed).

5.4.1.2 **Second-Order Neighbourhood Density**

As second-order neighbourhood density is reliant on first-order neighbours for its calculations, second-order neighbourhood density itself cannot be observed as an independent factor. As a result of this, in order to check the phone strings had their designated second-order neighbourhood density properties, statistical tests needed to be made within each first-order neighbourhood density group subgroup, i.e. checking low and high second-order neighbourhood density groups were significantly different within low first-order neighbourhood density words and pseudo-words, and similarly for high first-order neighbourhood density words and pseudo-words. Therefore, the *t*-tests carried out on second-order neighbourhood density were based within each first-order neighbourhood density group.

An independent samples *t*-test that compared low and high second-order neighbourhood density within words known at age 3 with high first-order neighbourhood density, showed a significant difference between the two groups, $t(10) = 3.992$, $p = .003$. Similarly, low and high second-order neighbourhood density were compared within words known at age 3 for the low first-order neighbourhood density stimuli. Levene's test was significant, $F = 12.090$, $p = .006$, so a t statistic not assuming homogeneity of variance was computed. A significant difference was found between the two groups, $t(5) = 3.410$, $p = .016$ (equal variances not assumed).

Using the same test on words not known until age 5 with low first-order neighbourhood density, significant effects for second-order neighbourhood density was found; $t(10) = 2.926$, $p = .015$. However, for low and high second-order neighbourhood density words within high first-order neighbourhood density words not known until age 5, Levene's test was significant, $F = 20.121$, $p = .001$, so a t statistic not assuming homogeneity of variance was computed. The result of the t-test showed no significant difference occurred between the two groups, $t(5) = 2.275$, $p = .072$ (equal variances not assumed). It is therefore important to keep this in mind when analysing the experimental effects of these word groups (5HH and 5HL words) in the word production tests.

The independent samples t-test that compared low and high second-order neighbourhood density within high first-order neighbourhood density pseudo-words, showed a significant difference between the two groups, $t(22) = 2.851$, $p = .009$. A significant effect was also found when low and high second-order neighbourhood density was compared within low first-order neighbourhood density pseudo-words, $t(22) = 8.711$, $p < .001$.

5.4.2 ***Properties of the stimuli***

Out of the 6,131 words known at age 3, only 5,509 words (89.9%) had any first-order word neighbours at age 3. The maximum number of neighbours any word had was 59, and the minimum number of neighbours was 3. Similarly, for those extra words that are not known until age 5, only 1,475 out of 2,575 (57.3%) had first-order word neighbours. There was a 32.6% drop in the number of words having neighbours at age 3 compared to those having neighbours at age 5. At age 5, the maximum number of neighbours a word had was 49 and the minimum was 1. These results indicated that the extra words learned between ages 3 and 5 years have less variation in the number of word neighbours they have compared to words known at age 3. It is also important to note that the number of words without neighbours greatly increases at age 5 (43.7%) compared to age 3 (11.1%), which could be a result of the types of words which are acquired at the later age. For words known at age 3, 2,478 out of 6,131 (40.4%) were monosyllabic, whereas for words not known until age 5 (excluding those already known at age 3), only 660 out of 2,575 words (25.6%) were monosyllabic. The difference between the number of monosyllabic words in the two groups could explain the drop in the number of words having neighbours at age 3 compared to age 5 as monosyllabic words have more word neighbours than multisyllabic words.

It was found in the computational analysis that words with high neighbourhood densities tended to be monosyllabic whereas words in low neighbourhood densities tended to be multisyllabic. Due to the nature of words with high and low neighbourhood density, there were very few words that matched in the properties specified by the selection criteria (spoken word frequency and number of syllables), which explains why only 6 words were obtained for each of the 12 categories.

5.4.3 *Comparison across all phone string categories*

In order to look at the changes of first- and second-order neighbourhood densities in words and pseudo-words across age, analyses were made on the properties of the phone strings chosen as stimuli. Figure 5-2 illustrates the mean number of first- and second-order neighbours across categories for those phone strings chosen as stimuli. There is a downwards trend from HH, HL, LH to LL categories across words and pseudo-words, where HH words have the highest number of first- and second-order neighbours followed by HL, LH and finally LL words.

From the graph it can be seen that there are more first- and second-order neighbours for word types at age 3 (3HH, 3HL, 3LH, 3LL) compared to those at age 5 (5HH, 5HL, 5LH, 5LL). In the case of the pseudo-words, the HH and HL categories have fewer first- and second-order neighbours than the corresponding word groups. However, for the LH and LL categories, the pseudo-words have a lower number of first- and second-order neighbours than words known at age 3, but a higher number of first- and second-order neighbours than words not known until age 5.

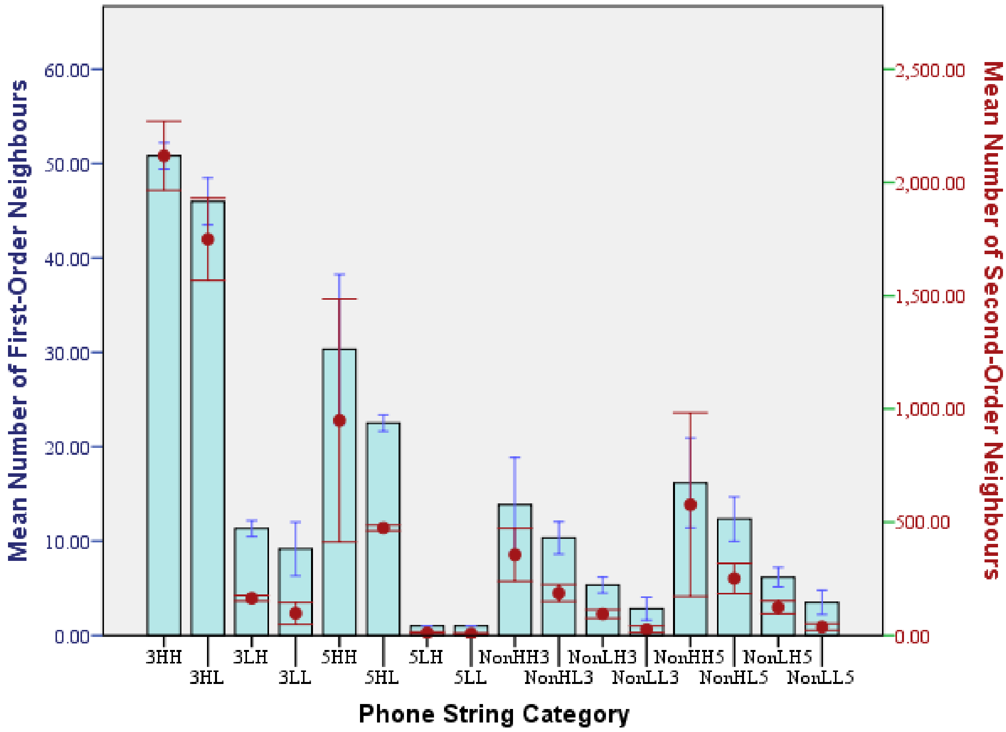

Figure 5-2. The mean number of first- and second-order neighbours across categories for those phone strings chosen as stimuli. Bars represent the mean number of first-order neighbours (left scale) and the circles represent the mean number of second-order neighbours (right scale). Error bars represent 95% confidence interval.

From the figure it appears that there are big differences across the stimulus sets, but it should be noted that the figure only illustrates the absolute mean of first- and second-order neighbourhood density values. This makes it difficult to see how each of these values differ from the mean of each phone string set (relative difference; i.e. the difference between the 3HH values from the group mean of HH, HL, LH and LL phone strings for words known at age 3). As the phone strings are bound to have variability in the number of first- and second-order neighbours because of age effects, the absolute differences are therefore not as important as the relative difference.

Recall that since the aim of the subsequent studies was to see whether the perception of a phone string that has a high or low number of first- and second-order neighbours influences production, in order to investigate the relative differences between the phone strings, the $\log_{10}$ of the number of first-and second-order neighbours was obtained first. Using the $\log_{10}$ data, the difference from the mean for the number of first- and second-order neighbour within each phone string set (words known at age 3, NK words at age 3, and pseudo-words) was calculated.

The comparisons which are of interest are the following: comparing words known at age 3 and non-words (grouping the pseudo-words with words not known until age 5, as these are treated as non-words for children under age 5), and comparing words not known until age 5 and pseudo-words. Comparing words known at age 3 and non-words (NK words and pseudo-words) is useful in studying children under age 5 as they would not have acquired the words not known until age 5 and would see those words as non-words along with the pseudo-words. Comparing words not known until age 5 and pseudo-words is helpful in studying older children (age 5 and above) who have acquired the words at age 5 and are processing them as words.

5.4.3.1 **Difference between words known at age 3 and non-words (NK words and pseudo-words)**

Using the newly calculated values of difference from the mean for the number of first- and second-order neighbours, comparisons were made between words known at age 3 and non-words. Figure 5-3 and Figure 5-4 show that when looking at the relative difference between words known at age 3 and non-words, the neighbourhood density variability is much smaller for the number of first- and second-order neighbours than for the absolute data illustrated in Figure 5-2. Independent samples *t*-tests across groups with high and low neighbourhood density combinations, i.e. comparing WordHH with NonHH, showed no significant differences (Appendix G).

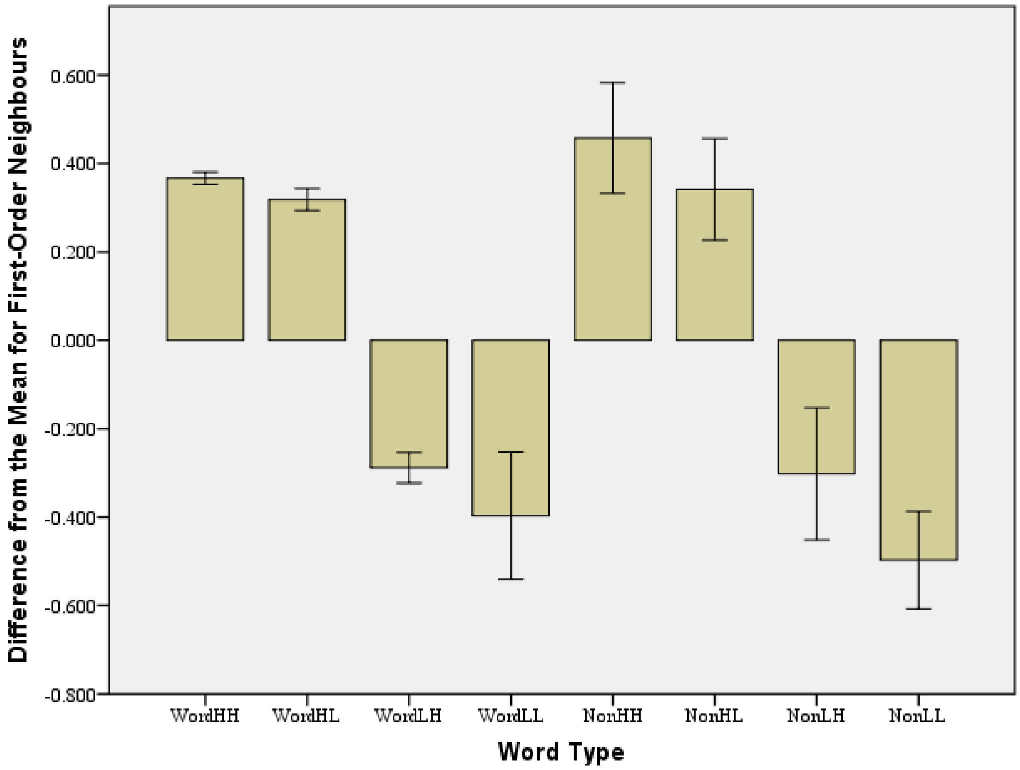

Figure 5-3. The mean difference from the mean of first-order neighbours within each stimulus set (words known at age 3 and non-words). Error bars represent 95% confidence interval.

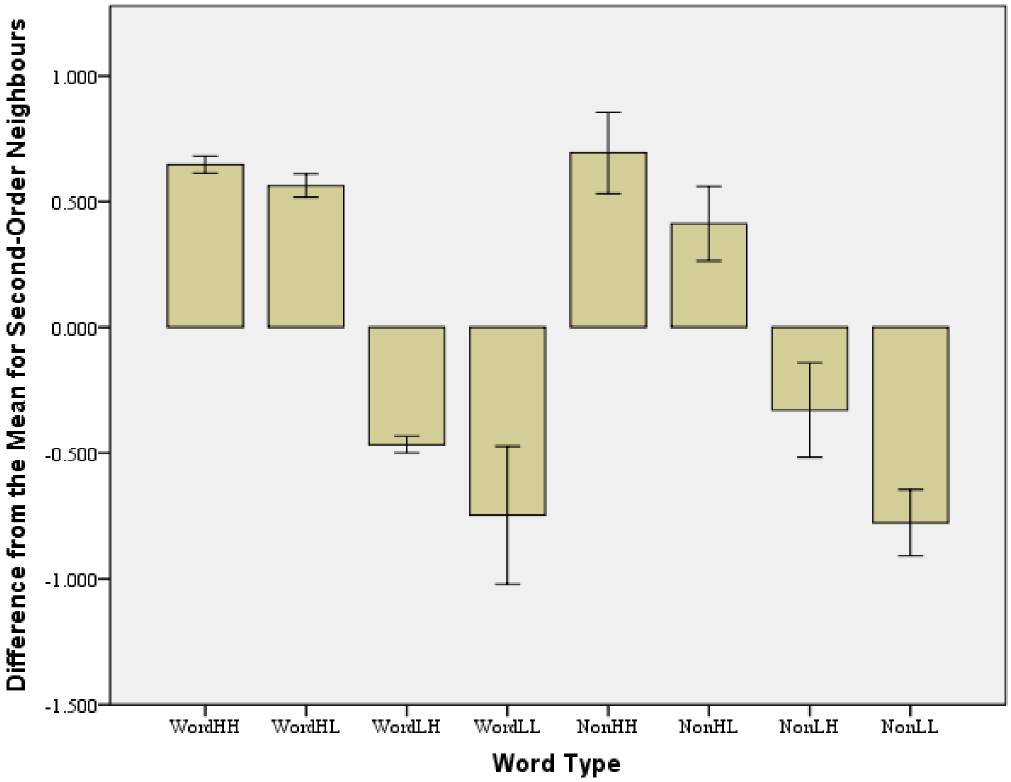

Figure 5-4. The mean difference from the mean of second-order neighbours within each stimulus set (words known at age 3 and non-words). Error bars represent 95% confidence interval.

5.4.3.2 **Difference between words not known until age 5 and pseudo-words**

Using the calculated values of difference from the mean for the number of first- and second-order neighbours, comparisons were made between words not known until age 5 and the set of pseudo-words. Figure 5-5 and Figure 5-6 show that when looking at the relative difference between the words and pseudo-words, there was variability across words and pseudo-words within each of the neighbourhood density categories (HH, HL, LH and LL). Independent samples *t*-tests across groups with high and low neighbourhood density combination, i.e. comparing WordHH with NonHH, showed significant differences across all comparisons (Appendix G).

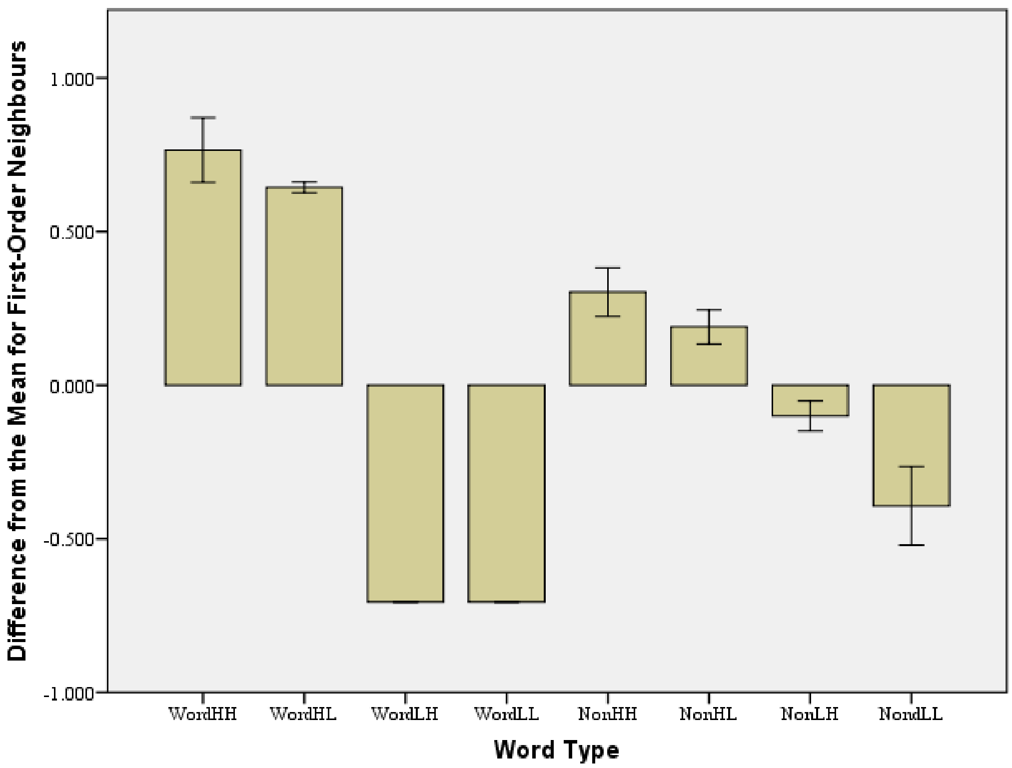

Figure 5-5. The mean difference from the mean of first-order neighbours within each stimulus set (words and pseudo-words). Error bars represent 95% confidence interval.

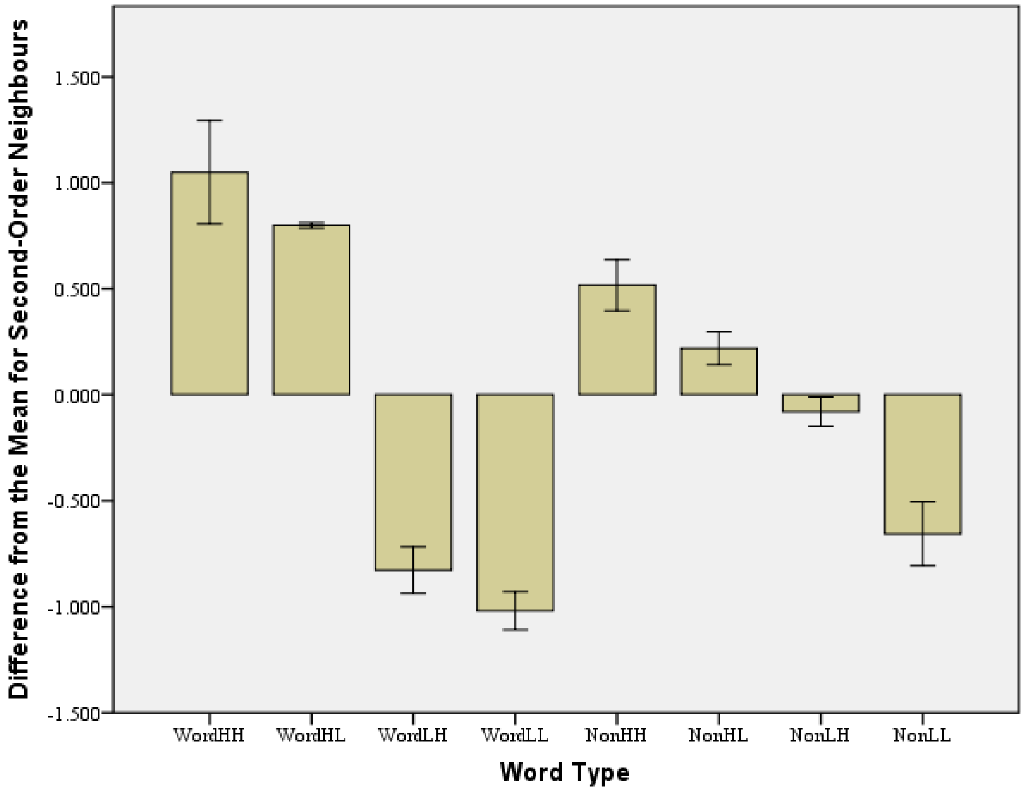

Figure 5-6. The mean difference from the mean of second-order neighbours within each stimulus set (words and pseudo-words). Error bars represent 95% confidence interval.

5.5 Discussion

The aim of the computational analyses was to obtain first- and second-order neighbourhood density statistics for words and pseudo-words at age 3 and 5, so that groups of phone strings could be selected for word production testing. Words and pseudo-words were controlled on a number of factors, which resulted in a small number of possible phone strings that could be used as stimuli.

Analysis of the final list of phone strings chosen revealed some trends in the number of first- and second-order neighbourhood densities across categories. There appears to be a lower number of words with first-order neighbours for words not known until age 5 compared to words known at age 3 (a 32.6% drop). The large drop in the number of words shows that words acquired later in development are less likely to have neighbours, quite possibly because more words are multisyllabic at age 5 compared to words acquired earlier in development (74.4% at age 5 compared to 59.6% at age 3). This illustrates a syllable shift over child language development as the words acquired in the lexicon move from monosyllabic to multisyllabic words. This implies that there could be stronger neighbourhood density effects at age 3 compared to at age 5. This is due to the larger number of words having neighbours and therefore connections with other words.

The results showed that the extra words learned between age 3 and age 5 show less variation in the number of word neighbours they have compared to words known at age 3. Once again this could have been caused by the shift to longer syllable words that occurs in language acquisition. These findings thus imply that as shifts in mean syllable length occur after age 3, neighbourhood density effects may also be weaker.

When comparing words known at age 3 with non-words (NK words and pseudo-words), the number of first and second-order neighbours are comparable across all first-and second-order neighbourhood density combinations (HH, HL, LH, LL), meaning that the stimuli here can be effectively compared in experimental testing.

However, when looking at the difference between words known after at 5 and pseudo-words, there are clear differences across all first-and second-order neighbourhood density combinations (HH, HL, LH, LL), indicating that words not known until age 5 and pseudo-words may not be comparable especially if the stimuli were used in experimental testing. However, the difference between words not known until age 5 and pseudo-words is important as it illustrates that there are fundamental differences between the two groups which could be the factor that makes a word different to a pseudo-word. As the set of pseudo-words was selected based on English phonotactic constraints, this shows that strings which are not in the English dictionary but obey rules based on the English language, have very small neighbourhood density differences compared to words that do exist in the English dictionary.

The improved methodology in the second computation analysis which includes multisyllabic words in the neighbourhood density calculations provided a more realistic representation of how the lexicon develops in early childhood. However, as the analysis on the phone string categories here was limited to a small number of phone strings selected based on a number of controlled factors, the first computational analysis may provide a better overview of how all monosyllabic words change in first- and second-order neighbourhood density over age. Furthermore, it should be noted that word age-of-acquisition statistics were obtained from CHILDES based on which words are spoken at what ages. It is possible that a child may know a word but did not speak it in the conversation recorded by CHILDES transcripts. However, as there are no age-of-acquisition databases that have data for all the words in the dictionary, this method is used in order to keep as many word items available before the selection criteria were applied.

Nonetheless, the second computational analysis is important as it provides much information for understanding early lexical network development, such as the difference between words and pseudo-words. Although these differences may mean more care is required when analysing the experimental effects of the stimuli, the differences are fundamentally important as they give a basis for understanding phone string processing differences.

The results from the analyses here also demonstrated clear differences between the phone string categories, where HH phone strings had the highest first- and second-order neighbourhood density, followed by HL, LH and LL phone strings. The differences between the groups were shown to be significant in the independent samples *t*-tests when second-order neighbourhood density was a factor within first-order neighbours, apart from the 5HH and 5HL categories. Overall, this means that if the selected phone strings were used in experimental testing, then any differences found in responses should be due to the specific phone string properties (first- and second-order neighbourhood density and whether it was treated as a word, NK word or pseudo-word). It is thus appropriate to use these phone strings to test children's word production responses, especially for the investigation of first-order neighbourhood density.

6 Chapter 6: Effects of Neighbourhood Density Changes over Development: An experimental study on word-non-word production in children

6.1 Introduction

The second computational analyses (Chapter 5) obtained first- and second-order neighbourhood density statistics for words and pseudo-words (non-words that follow phonotactic constraints that are never acquired into the lexicon) at ages 3 and 5, and stimuli were selected that differed on these properties. Depending on a child's age, phone strings from the three sets (words known at age 3 and 5, and set of pseudo-words) would be perceived differently depending on whether the child has acquired those words into their lexicon (a word/non-word difference). The Generative Acquisition Hypothesis Processing Shift Model (discussed in Chapter 2) predicts that words are processed lexically (as whole units) whilst non-words are processed sublexically (as separate phonemes). In turn, when a phone string is processed lexically or sublexically, the model predicts different influences of neighbourhood density. High neighbourhood density is predicted to facilitate sublexical processing but hinder lexical processing, whilst low neighbourhood density is predicted to do the opposite.

To assess the predictions made by the model, word/non-word status needs to be established for children in two age groups (under age 5 and over age 5). The two age groups were tested for their repetition accuracy on the three phone string sets.

The three phone string sets that were obtained were: words known at age 3 (words which are known by children from age 3 which would be known by both the under 5 and over 5 age groups), words only known at age 5 and above, and pseudo-words (non-words at all ages including both the under 5 and over 5 age groups).

The same two comparisons between phone string sets that were performed in Chapter 5 were made here (see below). In the experiment, both age groups (younger, older) were tested on the two comparisons to establish whether there were any age-dependent effects (i.e. whether or not a child has acquired the stimulus as a word).

For Comparison One, words not known until age 5 and above were collapsed with pseudo-words to create a set termed ‘non-words’. The collapsed set of ‘non-words’ was compared with words known at age 3, which are words that are known by both age groups.

Comparison of the words known at age 3 with ‘non-words’ allows the word/non-word effects of the phone strings to be tested for the under-5 age group, as they would process the words known at age 3 as words, and the non-word set as non-words. Words known at age 3 were used to ensure that the under-5 children who were tested would have all acquired these words. The children over age 5 would treat the words not known until age 5 in the non-word set as words, but would treat the pseudo-words as non-words. Table 6-1 summarizes how children under, and over, age 5 were expected to perceive the phone strings for these two sets of stimuli.

Table 6-1. *Indications of whether children of different ages perceive phone strings as either words or non-words. The 'non-word' set is defined with respect to the younger age group, so it includes phone strings that are only acquired as words at age 5.*

Age of Participants	Words known at age 3	Non-words (including words not known until age 5)
Under 5 (younger)	Words	Non-words
Over 5 (older)	Words	Some treated as words, some treated as non-words

For Comparison Two, words not known until age 5 and above (not known at age 3) were compared with pseudo-words. Children over age 5 would treat the words not known until age 5 as words and the pseudo-word as non-words. Comparison of words not known until age 5 and pseudo-words allows word/non-word effects to be established for the children aged 5 and over. Children under age 5 should process the words learned at age 5 as non-words in the same way that children over age 5 will process pseudo-words. Table 6-2 summarizes how children under 5, and 5 and over should perceive the stimuli for these two phone string sets.

Table 6-2. *Indications of whether children of different ages perceive phone strings (words known only at age 5 and pseudo-word) as either words or non-words.*

Age of Participants	Words not known until age 5	Pseudo-words
Under 5 (younger)	Non-words	Non-words
Over 5 (older)	Words	Non-words

When the stimulus properties of the phone string sets were compared in the computational analyses in Chapter 5, there were no significant differences in the relative difference analysis in the variability of phone string neighbours between each category (HH, HL, LH and LL) for words known at age 3 and the collapsed set of non-words appropriate for the younger age group (Comparison One). However, when words not known until age 5 were compared with pseudo-words, there were significant differences in the variability of phone string neighbours between each category (HH, HL, LH and LL) in the relative difference analysis (Comparison Two). This was shown using independent samples *t*-tests across the two phone string sets with high and low neighbourhood density combinations (HH, HL, LH, LL); HH, HL, LH and LL words compared with their pseudo-word counterparts.

Therefore, results from Comparison One are more legitimate than results from Comparison Two, as there is no significant variability between the two stimuli sets, thus they are comparable. The second comparison, between words not known until age 5 against pseudo-words would therefore require more caution as there is more variability between the phone string sets in this case based on the relative difference analysis.

The Generative Acquisition Hypothesis Processing Shift Model (discussed in Chapter 2) explains that in the case of words, phonemes are fed into short-term memory through bottom-up processing, with top-down matching occurring simultaneously. The top-down process matches chunks of inputted phonemes together as one unit to see if they match any of the known words in the lexicon. This is described as lexical processing. Non-word processing differs from word processing as the former has to be processed sublexically, which means that only bottom-up analysis occurs where phone strings are processed as phonemes or phoneme chunks. This arises because the inputs cannot be processed as a unit, precluding top-down influences, because the non-word does not exist within the lexicon. Consequently, repetition accuracy in the experimental study was predicted to differ depending on whether a phone string was processed as a word or a non-word.

As indicated in Table 6-1 and Table 6-2, phone strings from the different phone string sets are treated as either words or non-words by children under 5, and 5 and over. Looking at the different types of material, the set of words known at age 3 should be processed lexically (as words), and the set of pseudo-words should be processed sublexically (as non-words) for all children (under and over age 5). The set of words not known until age 5 would be processed differently depending on participants' ages, as this determines whether they have acquired the word into the lexicon or not and this determines whether the set is processed lexically or sublexically. In particular, it was predicted that children under age 5 who have not acquired the words would treat them as non-words and process them sublexically whereas children aged 5 and over would have acquired the words and therefore would process them lexically. Consequently, neighbourhood density properties of the phone strings from the three groups would have different effects based on whether the phone string was treated as a word or a non-word. Table 6-3 and Table 6-4 summarize the predictions of how the phone strings from the different sets are processed by participants of different ages.

Table 6-3. *Predictions of how words known at age 3 and non-words (including words not known until age 5) would be processed by participants of different ages.*

Age of Participants	Words known at age 3	Non-words (including words not known until age 5)
Under 5 (younger)	Lexical	Sublexical
Over 5 (older)	Lexical	Lexical and Sublexical

Table 6-4. *Predictions of how words known only at age 5 and pseudo-words would be processed by participants of different ages.*

Age of Participants	Words not known until age 5	Pseudo-words
Under 5 (younger)	Sublexical	Sublexical
Over 5 (older)	Lexical	Sublexical

First-order neighbourhood density effects should be stronger than second-order neighbourhood density effects as first-order neighbours have direct links with the target word. Also, words with high neighbourhood density should show more lateral inhibition. Therefore, it was hypothesised that in the case of words, the HH set would have lowest accuracy, followed by HL, LH and LL word types. On the other hand, non-words with a higher number of first- and second-order neighbours would be produced more accurately than non-words with a lower number of first- and second-order neighbours, as phoneme chunks that are shared with words activate word candidates in a bottom-up fashion that, in turn, facilitates non-word production. In contrast to words, HH would therefore be the most accurate, followed by HL, LH and LL non-words.

6.2 Experiment Two

The current experiment used the stimuli obtained in the second computational analysis (Chapter 5) to test children's word and non-word production performance. These stimuli avoided the limitations of the materials generated in Chapter 3 by extending analysis to pseudo-words, words not known for 3-year-olds and multisyllabic materials. It was predicted by the Generative Acquisition Hypothesis Processing Shift Model that processing for the phone strings would be different based on whether they are perceived as a word or non-word, and that neighbourhood density effects would then depend on whether lexical (top-down) or sublexical (bottom-up) processing is taking place.

As the picture-naming task in Experiment One (Chapter 4) was demanding in terms of attention required from the young children, the reaction times obtained in the experiment may have been variable due to individual differences between children. To address this, a repetition task was used instead of the picture-naming task to see if it provided clearer evidence for production differences between phone string categories.

Gathercole (2006) argues that non-word repetition tasks only require participants to access the phonological loop and do not require lexical processing. This is supported by studies that show effects of phonological memory on repetition performance (Gathercole & Baddeley, 1990). However, more recent research has shown that non-word repetition tasks correlate significantly with speech output, as measured in picture naming tasks (Norbury, Tomblin, & Bishop, 2008). In the study by Norbury et al., (2008), repetition was found to reduce memory demands. By using word repetition in the current experiment, phonological memory effects would be unlikely to influence the results. Previous studies in neighbourhood density have used repetition tasks to test for neighbourhood density effects (Garlock et al., 2001; Lipinski & Gupta, 2005; Vitevitch & Luce, 2005).

Children's repetition accuracy (whether they produced the phone string presented correctly) was used in the analyses instead of reaction times because of the variability that was seen in the reaction time data in Experiment One (Chapter 4). Secondly, to investigate the shifts from non-word to word processing, children in two age groups were used in the current experiment: the age groups were under age 5, and 5 and above. For children under age 5, only words known at age 3 were considered to be words, however for children aged 5 and above, words known at age 3 and 5 were considered to be words. Thus, there should be age effects on word repetition accuracy depending on the participant's age and which stimulus set was being processed.

6.3 Method

6.3.1 *Participants*

6.3.1.1 Children under age 5

Parents of 25 children from three different nurseries in London consented to their child's participation in the experiment. Out of the 25 children, 20 (8 males, 12 females) successfully completed both the BPVS (Dunn et al., 1982) control test and the word repetition task. The other five children were either unable to complete the BPVS or the word repetition task due to lack of concentration, or requested that they be withdrawn from the experiment. To prevent extraneous variables affecting the results, any participants who stated that they were bilingual (N = 4) were removed from the analysis, as the existence of vocabulary from another language could affect the lexical connections present in an English lexicon. One child with reported glue ear was also removed from the analysis. This left 15 children in the analysis that is reported (5 males, 10 females). The mean age of these children was 3 years and 6 months (range 2 years 9 months to 4 years 7 months). Although two of the children were under age 3, their BPVS scores indicated they were at a comparable level to the other participants and so they were included in the analyses.

6.3.1.2 Children 5 and over

Parents of 28 children (12 males, 16 females) from schools in London and Milton Keynes consented that their child could participate in the experiment. As with the younger age group, bilingual children and children with speech and hearing disorders were dropped from the sample. This left 16 children in the analysis that is reported (4 males, 12 females). The mean age of these children was 6 years and 10 months (range 5 years 2 months to 8 years 10 months).

6.3.2 *Stimuli*

The final list of word-non-word stimuli obtained from the second Computational Analysis (Chapter 5) were transformed into audio files using an online text to speech program Acapela ('Acapela Text to Speech Demo', n.d.). The program output is an audio version of the phone strings in a Standard English accent using an English male adult voice. This is an accent to which children in the South East and London areas would be regularly exposed. All audio outputs were played to adult listeners to ensure they were intelligible. The audio files were saved in .wav format, which is a lossless format that would allow for maximum intelligibility instead of using a compressed lossy format such as .mp3, for replay at test. Phonetic transcriptions of the phone strings using SAMPA coding are given in Appendix F. As the Acapela program uses recordings from narrators on a series of texts for its acoustic database, it maximises the speech's naturalness and intelligibility.

There are mixed findings regarding the effect of synthetic or natural speech on speech perception (Clark, Dermody, & Palethorpe, 1985; Luce, Feustel, & Pisoni, 1983; Schwab, Nusbaum, & Pisoni, 1985). On the one hand, some studies have shown that identification accuracy is enhanced for natural speech but not for synthetic speech (Clark et al., 1985). On the other hand, other studies have shown that word recognition performance was better in groups who have been trained with synthetic speech over natural speech (Schwab et al., 1985). However, as pseudo-words are used in this experiment it was decided to synthesize the stimuli as they are difficult to produce naturally and this could affect results.

Following the second Computational Analyses (Chapter 5) there was a total of 48 words and 48 pseudo-words in the stimulus sets. The pseudo-word sets contained the same pseudo-words at ages 3 and 5 except that two pseudo-words swapped neighbourhood density categories across age groups (from HL to HH and HH to HL). Hence, it was decided that for the behavioural experiment the list of pseudo-words would only be presented once during the test to reduce fatigue effects, but would be analysed as pseudo-words at age 3 and pseudo-words at age 5 in the analysis. Using one pseudo-word set halved the number of items in the stimulus set (to 24), and the two pseudo-words that changed neighbourhood densities over age were dropped from the analysis to keep the designation as pseudo-words applicable to both age groups. Thus the set of stimuli used in testing consisted of 48 words and 22 pseudo-words (70 in total).

6.3.3 *Procedure*

Children were first tested on the British Picture Vocabulary Scale (BPVS) long form to ensure that their spoken vocabulary understanding was comparable to children of the same age. The procedure followed that used in Experiment One (Chapter 4).

After the BPVS test, children performed the spoken repetition task. Children were requested to listen to audio files played from the computer over headphones and were asked to repeat exactly what they had heard. After each response from the child, the experimenter acknowledged the response by nodding her head. The experiment was paced by the experimenter and the next phone string was only presented when the experimenter felt the child had finished with one response and was ready for the next. This allowed a break between each stimulus.

Three practice trials were given to ensure that the participants understood the instructions. Trials were repeated until each child reproduced all three practice phone strings correctly. After the practice trials, participants were presented with the 70 word and pseudo-word stimuli in a randomised order and their responses recorded using the program Audacity. For the analysis, only children's accuracy of repetition on each phone string was scored as reaction times varied greatly across children (i.e. the reaction time data were noisy).

Children's recordings on the repetition task were played back so that their responses could be scored by the experimenter. Responses to the phone strings were scored as correct or incorrect based on whether the whole phone string was repeated accurately or not. All phonemes in the phone string presented had to be reproduced correctly for the string to be counted as correct. The requirement here was to record whole-word processing, not accuracy of production of particular phonemes. As individual phoneme accuracy does not reflect whole-word processing, which is the aim of the current experiment, whole phone string accuracy was used.

The average child cannot accurately produce certain phonemes such as /k/ until around age 4 because of the 'fronting' process (place of articulation brought forward from velar to an alveolar position) (Berry & Eisenson, 1956; Grunwell, 1982). This may cause validity problems in scoring. However, studies in non-word repetition (such as Children's Test of Non-word Repetition (Gathercole, Willis, Baddeley, & Emslie, 1994)) use this form of scoring as it cannot be assumed that a child uses the process of ‘fronting’ consistently without conducting a systematic analysis of the individual child’s phonological system. Consequently, it cannot be assumed that the under age 5 group would have ‘fronting’ and the 5 and over group would not. As the task duration and the demand of the BPVS and the repetition test were demanding for the children, it was decided that the same method of scoring as Gathercole et al., (1994) would be used in this experiment as time did not permit a systematic analysis of the child’s phonological system to be conducted. The same experimenter scored all responses to ensure scoring reliability. Results

The standardised score of the participants in the younger age group on the BPVS test was 103.67 (range 81 to 123) and for the older age group was 105.74 (range 81 to 126). A BPVS standard score of 100 is the norm, and the natural variation range is between 85 and 115. Although some of the BPVS scores of the children fell slightly outside this range, a boxplot of the data showed that all the scores were within 1.5 times the interquartile range so they were not considered as outliers. Based on this, no further children were excluded from the analysis.

Data analysis investigated the effects of children’s age on repetition performance on phone strings (words and pseudo-words) with different first- and second-order neighbourhood densities. Based on the arguments made in Chapter 4 regarding the effect of second-order neighbourhood density, this was not analysed as a separate factor but as a factor within the factor of first-order neighbourhood density in the analyses. Therefore any analyses that mention second-order neighbourhood density involve examination of the four phone string categories (HH, HL, LH and LL) within each stimulus set. This helps determine whether there are neighbourhood density differences between the sets of word and pseudo-words.

Based on the comparison between the three phone string sets made in Chapter 5 (words known at age 3, words not known until age 5 and over, and pseudo-words), the first analysis (Comparison One) here looked at the difference between words known at age 3 and non-words (including those words not known until age 5, as they are treated as non-words by children under 5) and the second analysis (Comparison Two) looked at the difference between words not known until age 5 and pseudo-words.

As in Experiment One (Chapter 4), first- and second-order neighbourhood density could not be treated as random factors in the analysis. Thus, in the analysis these factors were entered into the model separately as fixed factors. Each participant's response to a phone string is scored per row in SPSS so for each participant there were 70 responses (rows) for them.

The presentation of the results is organised under the two comparisons mentioned above (Comparison One and Comparison Two). Within each comparison, first- and second-order neighbourhood density are analysed separately. For both first- and second-order neighbourhood density analyses comparisons were made between the neighbourhood densities of the phone strings within and between the word and non-word sets being investigated.

Within comparisons are those that look at phone strings with different neighbourhood density within words and non-words (words that are not known for Comparison One and pseudo-words for Comparison Two). For example, looking at the difference between words known at age 3 with different high and low first-order neighbourhood density properties. The results from this help to determine whether there are neighbourhood density effects within words and non-words.

Between comparisons are those that look at phone strings with the same neighbourhood density across words and non-words (words that are not known for Comparison One and pseudo-words for Comparison Two). For example, an analysis in Comparison One would be the difference between words known at age 3 and the non-word set with high first-order neighbourhood density. The results from this help to establish whether there are processing differences (lexical and sublexical) for phone strings with the same neighbourhood density but different word/non-word status.

6.3.4 *Comparison One: Difference between words known at age 3 and non-words (including those not known until age 5)*

Statistical tests were conducted to investigate the effects of first- and second-order neighbourhood density and word/non-word effects (whether a phone string is treated as a word or a non-word) in the repetition accuracies of children in different age groups (under 5, and 5 and over).

The goal of the separate analyses of variances (ANOVAs) conducted for these two phone string sets and the results of the corresponding Levene's test are shown in Table 6-5 (each row represents one analysis of variance conducted). The 'Goal' column shows the rationale for the statistical test conducted and the 'Factors in Analysis of Variance' column indicates which factors were inputted into the analysis of variance model. The column indicating 'Results of Levene's Test', checks whether homogeneity of variance of the groups can be assumed. When Levene's test was significant (equal variances not assumed), a more stringent significance level was needed to interpret the results to account for the unequal variances of the groups (Weiner, Schinka, & Velicer, 2003). Here an adjusted significance value of $p < .01$ was used for all analyses where Levene's test was significant. These analyses and their results are discussed in the following sections.

Table 6-5. *Goal and results of Levene's test for the ANOVAs conducted.*

	Goal	Factors in Analysis of Variance	Results of Levene's Test	Adjusted Significance
1	To see if the two age groups both process the words known at age 3 lexically (as known words), and thus have the same neighbourhood density effects	Impact of age group (younger, older) on the repetition accuracy for words with different first-order (high, low) neighbourhood densities	$p < .001$	$p < .01$
2	To see if the two age groups process the non-words differently (lexically and sublexically) and thus have different first-order neighbourhood density effects	Impact of age group (younger, older) on the repetition accuracy for the set of non-words with different first-order (high, low) neighbourhood densities	$p < .001$	$p < .01$
3	To see if word/non-word status affects the processing of phone strings with the same first-order neighbourhood densities	Impact of age group (younger, older) on the repetition accuracy of phone strings with different first-order (high, low) neighbourhood densities	$p < .001$	$p < .01$
4	To see if the two age groups process the words known at age 3 lexically and thus have the same second-order neighbourhood density effects	Impact of age group (younger, older) on the repetition accuracy for words with different second-order neighbourhood densities (HH, HL, LH, LL)	$p < .001$	$p < .01$
5	To see if the two age groups process the non-words differently (lexically and sublexically) and thus have different second-order neighbourhood density effects	Impact of age group (younger, older) on the repetition accuracy for the set of non-words with different second-order neighbourhood densities (HH, HL, LH, LL)	$p < .001$	$p < .01$
6	To see if word/non-word status affects the processing of phone strings with the same second-order neighbourhood densities	Impact of age group (younger, older) on the repetition accuracy of phone strings with different second-order neighbourhood densities (HH, HL, LH, LL)	$p < .001$	$p < .01$

6.3.4.1 **First-Order Neighbourhood Density**

6.3.4.1.1 Comparison of high and low first-order neighbourhood density phone strings within words and non-words

Table 6-6 shows the descriptive statistics for the repetition accuracy of children under and over age 5 on words and non-words with high and low first-order neighbourhood densities. To see if the two age groups both process the words known at age 3 lexically (as known words), and therefore have the same neighbourhood density effects, a two-way, between-groups analysis of variance was conducted (Row 1, Column 1 of Table 6-5). The analysis of variance assessed the impact of the two age groups (younger, older) on participants' repetition accuracy for words with different first-order (high, low) neighbourhood densities at age 3 (Row 1, Column 2 of Table 6-5). Levene's test for equality of error variances was significant, $p < .001$, so a more stringent significance level of $p < .01$ was used to evaluate the results from the analysis (Row 1, Column 3 and 4 of Table 6-5). This adjusted significance level was used for all analysis where Levene's test was significant.

No significant interaction was found between age and first-order neighbourhood density (Table 6-7). This indicated that the first-order neighbourhood density of the words known at age 3 had no effect on the word repetition accuracies of either the younger or the older children. The main effects of both factors were not significant either.

Table 6-6. *Descriptive statistics for the repetition accuracy of high and low first-order neighbours in children under and over 5 for words and non-words.*

	Age	First-order Neighbours	*N*	*M*	*SD*
Word	Under 5	High	180	.778	.417
		Low	180	.806	.397
	Over 5	High	192	.875	.332
		Low	192	.802	.400
Non-word	Under 5	High	360	.773	.420
		Low	360	.758	.429
	Over 5	High	384	.855	.353
		Low	384	.870	.337

Table 6-7. *Results from two-way between-groups analysis of variance for the factors first-order neighbourhood density and age for words known at age 3 and non-words. Those marked with an asterisk were significant (a p of < .01 was needed for significance).*

	Factors	*df*	*F*	*p*	Partial eta squared
Word	First-Order Neighbourhood Density and Age Interaction	(1, 743)	3.146	.077	.004
	Main Effect of First-Order Neighbourhood Density	(1, 743)	.632	.427	.001
	Main Effect of Age	(1, 743)	2.727	.099	.004
Non-word	First-Order Neighbourhood Density and Age Interaction	(1,1425)	.506	.477	< .001
	Main Effect of First-Order Neighbourhood Density	(1,1425)	< .001	.994	< .001
	Main Effect of Age	(1,1425)	22.500	< .001*	.016

A similar two-way between-groups analysis of variance was conducted for non-words. Row 2 in Table 6-5 describes the goal and results of Levene's test for this analysis. The results of the analysis of variance show that no significant interaction effect was found between age and first-order neighbourhood density, indicating that the first-order neighbourhood density of the non-words had no effect on the repetition accuracies of both younger and older children (Table 6-7). No main effect of first-order neighbourhood density was found either. However, a main effect of age was found, where the older age group (*M* = .863, *SD* = .344) was more accurate than the younger age group for the non-words (*M* = .765, *SD* = .424).

6.3.4.1.2 Comparison of high and low first-order neighbourhood density phone strings between words and non-words

As with the within word and non-word comparisons previously, to see if word/non-word status affects the processing of phone strings with the same first-order neighbourhood densities, a two-way, between-groups analysis of variance was conducted as described in Row 3 of Table 6-5.

Table 6-8 shows the results from the analysis of variance. Only a main effect of age was found between words known at age 3 and non-words with high first-order neighbourhood densities, where the older age group (*M* = .862, *SD* = .345) was more accurate than the younger age group (*M* = .775, *SD* = .418). However, the main effect of age for words known at age 3 and non-words with low first-order neighbourhood density also approached significance. Once again the older age group (*M* = .847, *SD* = .360) was more accurate than the younger age group (*M* = .774, *SD* = .419).

Table 6-8. *Results from two-way between-groups analysis of variance for the factors high and low first-order neighbourhood density and age between words known at age 3 and non-words. Those marked with an asterisk were significant or approached significance (a p of < .01 was needed for significance).*

First-Order Neighbourhood Density	**Factors**	***df***	***F***	***p***	**Partial eta squared**
High	First-Order Neighbourhood Density and Age Interaction	(1, 1053)	.090	.764	< .001
	Main Effect of First-Order Neighbourhood Density	(1, 1053)	.255	.613	< .001
	Main Effect of Age	(1, 1053)	13.250	< .001*	.012
Low	First-Order Neighbourhood Density and Age Interaction	(1, 1115)	5.411	.020*	.005
	Main Effect of First-Order Neighbourhood Density	(1, 1115)	.172	.679	< .001
	Main Effect of Age	(1, 1115)	4.777	.029*	.004

Although the first-order neighbourhood density and age interaction did not reach significance because a stringent significance level was used to evaluate the results, a *p* value of .020 would normally have been considered significant. Therefore it could be argued that if a larger number of participants were sampled, a significant effect could have been obtained for this interaction effect. Therefore this result could be interpreted as approaching significance. From this point onwards, all results approaching significance will be discussed.

Figure 6-1 shows the interaction between words and non-words and age for low first-order neighbourhood density material. It appears that the repetition accuracy of children in both age groups is similar for words with low first-order neighbourhood density, whereas there is a large increase in repetition accuracy for the older age group when non-words with low first-order neighbourhood density were repeated.

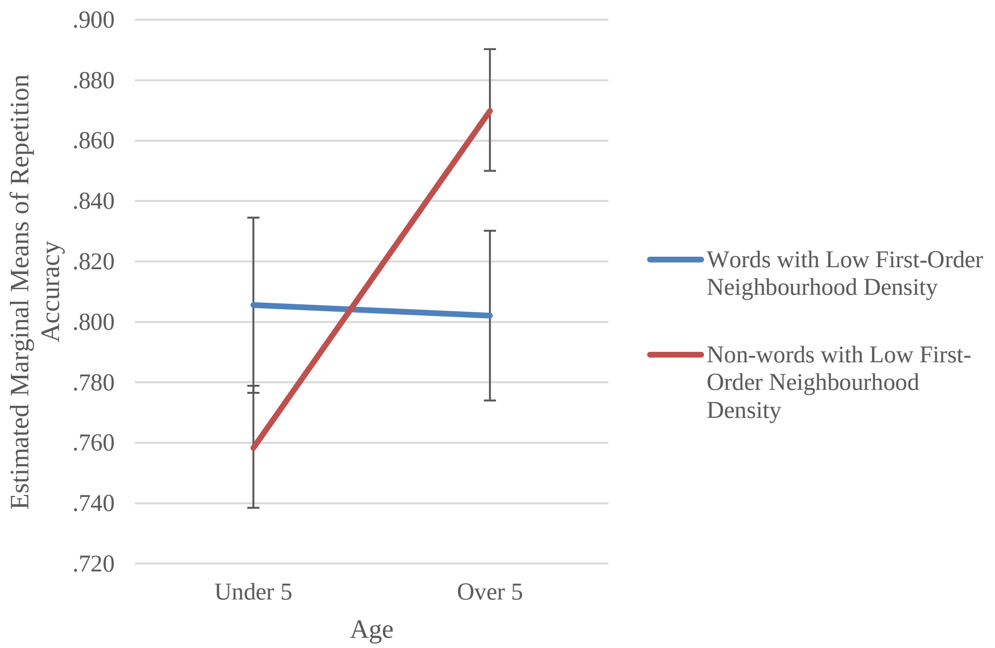

Figure 6-1. Plot illustrating the estimated marginal means of repetition accuracy with words and non-words with low first-order neighbourhood density across ages. Error bars indicate standard errors.

6.3.4.2 **Second-Order Neighbourhood Density**

6.3.4.2.1 Comparison of HH, HL, LH, and LL within words and non-words

Table 6-9 gives the descriptive statistics for the repetition accuracy of children under and over age 5 on words and non-words in the different second-order neighbourhood density groups (HH, HL, LH, LL). As with the analysis done with first-order neighbourhood density, two-way between-groups analysis of variance was conducted for: 1) words, 2) non-words. The goal and results of Levene's test for these are shown in Row 4 and 5 of Table 6-5.

For the analysis of variance on words, as with the results for first-order neighbourhood density, no significant interaction was found between age and second-order neighbourhood density (Table 6-10). This indicated that the second-order neighbourhood density of the words known at age 3 had no effect on the word repetition accuracies of both younger and older children. There were also no main effects of either of the factors.

For the analysis of variance on non-words, no significant interaction was found between age and second-order neighbourhood density (Table 6-10). With the more stringent significance level, no main effect of second-order neighbourhood density was found. However, there was a significant effect of age, where the older age group (M = .863, SD = .344) was more accurate than the younger age group (M = .765, SD = .424).

Similar to the interaction effect between low first-order neighbourhood density and age interaction, the main effect of second-order neighbourhood density approached significance. *Post hoc* tests using the Bonferroni correction indicated that there was a significant difference between LH (M = .777, SD = .417) and LL non-words (M = .855, SD = .353), p = .034, which is a possible indication of a second order neighbourhood density influence.

Table 6-9. *Descriptive statistics for the repetition accuracy of second-order neighbourhood groups (HH, HL, LH, LL) in children under and over 5 for words and non-words.*

	Age	**Second-order Neighbours**	***N***	***M***	***SD***
Word	Under 5	HH	90	.733	.444
		HL	90	.822	.385
		LH	90	.789	.410
		LL	90	.822	.385
	Over 5	HH	96	.854	.355
		HL	96	.896	.307
		LH	96	.823	.384
		LL	96	.781	.416
Non-word	Under 5	HH	165	.806	.397
		HL	165	.739	.440
		LH	180	.706	.457
		LL	180	.811	.393
	Over 5	HH	176	.847	.361
		HL	176	.864	.344
		LH	192	.844	.364
		LL	192	.896	.306

Table 6-10. *Results from two-way between-groups analysis of variance for the factors second-order neighbourhood density and age for words known at age 3 and non-words. Those marked with an asterisk were significant or approached significance (a p of < .01 was needed for significance).*

	Factors	***df***	***F***	***p***	**Partial eta squared**
Word	Second-Order Neighbourhood Density and Age Interaction	(1, 743)	1.455	.226	.006
	Main Effect of Second-Order Neighbourhood Density	(1, 743)	1.095	.350	.004
	Main Effect of Age	(1, 743)	2.726	.099	.004
Non-word	Second-Order Neighbourhood Density and Age Interaction	(1,1425)	1.143	.330	.002
	Main Effect of Second-Order Neighbourhood Density	(1,1425)	2.843	.037*	.006
	Main Effect of Age	(1,1425)	22.614	< .001*	.016

6.3.4.2.2 Comparison of HH, HL, LH, and LL between words and non-words

To see whether word/non-word status affects the processing of phone strings with the same neighbourhood densities, four two-way, between-groups analyses of variance were conducted. The goal and the results of Levene's test for these are in Row 6 of Table 6-5. Essentially HH words were compared with HH non-words, HL words were compared with HL non-words, LH words were compared with LH non-words, and LL words were compared with LL non-words.

A main effect of age was found between words known at age 3 and non-words for the LL set (Table 6-11). It was found that the HH and LH sets also approached significance. For all the sets that showed significant or near-significant effects, the older age group was more accurate than the younger age group.

Table 6-11. *Results from four two-way between-groups analysis of variance for the different second-order neighbourhood density groups (HH, HL, LH and LL) and age between words known at age 3 and non-words. Those marked with an asterisk were significant or approached significance (a p of < .01 was needed for significance).*

Second-Order Neighbourhood Density	**Factors**	***df***	***F***	***p***	**Partial eta squared**
HH	Second-Order Neighbourhood Density and Age Interaction	(1, 526)	1.296	.255	.002
	Main Effect of Second-Order Neighbourhood Density	(1, 526)	.853	.356	.002
	Main Effect of Age	(1, 526)	5.234	.023*	.010
HL	Second-Order Neighbourhood Density and Age Interaction	(1, 526)	.540	.463	.001
	Main Effect of Second-Order Neighbourhood Density	(1, 526)	2.787	.096	.005
	Main Effect of Age	(1, 526)	8.245	.004*	.016
LH	Second-Order Neighbourhood Density and Age Interaction	(1, 557)	2.030	.155	.004
	Main Effect of Second-Order Neighbourhood Density	(1, 557)	.731	.393	.001
	Main Effect of Age	(1, 557)	5.550	.019*	.010
LL	Second-Order Neighbourhood Density and Age Interaction	(1, 557)	3.611	.058*	.006
	Main Effect of Second-Order Neighbourhood Density	(1, 557)	2.447	.118	.004
	Main Effect of Age	(1, 557)	.438	.509	.001

Although the LL set did not show any significant main effect of age, it can be seen that for this set the second-order neighbourhood density and age interaction approached significance, $p = .058$. Figure 6-2 shows the interaction effect present between words and non-words with low first- and second-order neighbourhood density. It appears that the repetition accuracy of children in the younger age group was similar for LL words and non-words, however, for the older age group there was a clear difference in that LL words were produced less accurately than the LL non-words.

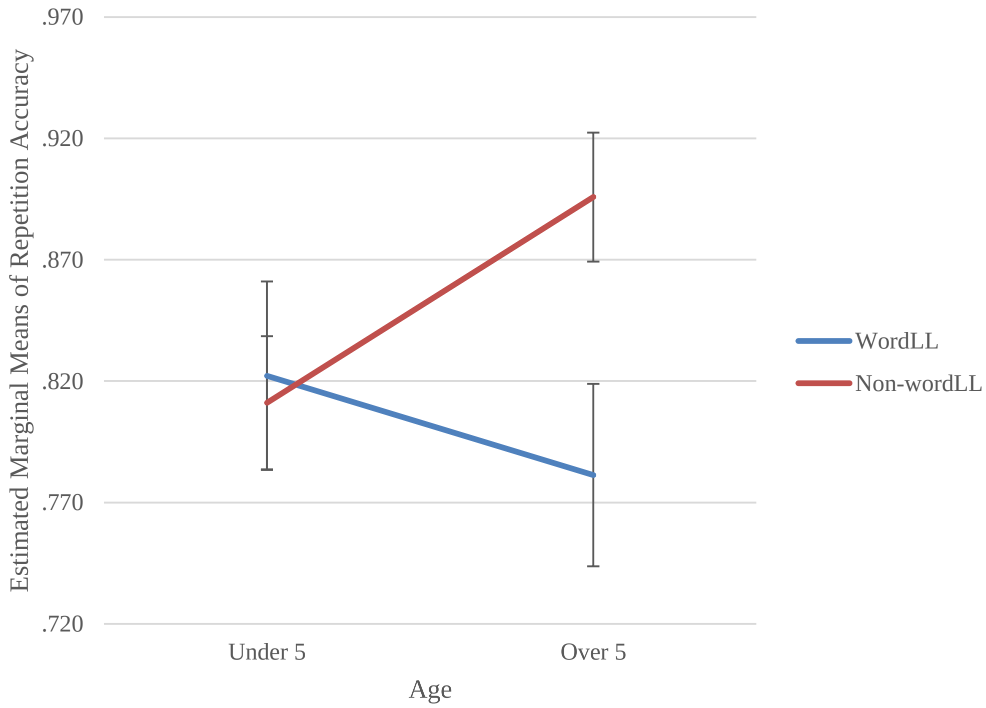

Figure 6-2. Plot showing the estimated marginal means of repetition accuracy with words and non-words with low first- and second-order neighbourhood density across ages. Error bars indicate standard errors.

6.3.5 *Comparison Two: Difference between words not known until age 5 and pseudo-words*

Statistical tests were conducted to investigate the effects of first- and second-order neighbourhood density and word-non-word effects (whether a phone string was treated as a word or a non-word) in the repetition accuracies of children in different age groups (under 5 and over 5). This time comparison was made between words not known until age 5 and the set of pseudo-words.

Table 6-12 summarizes the goals of the analyses of variance conducted for Comparison Two. The results of Levene’s test, which checks the homogeneity of variance of the groups, are shown. In the cases where Levene's test was significant, equal variances of the groups cannot be assumed so a more stringent significance level ($p < .01$) was adopted for the interpretation of the results (Weiner et al., 2003). Each row in the table represents one analysis of variance conducted. This is laid out in the same way as Table 6-5 for Comparison One. These analyses and their results are discussed in the following sections.

Table 6-12. *Goal and results of Levene's test for the ANOVAs conducted.*

	Goal	Factors in Analysis of Variance	Results of Levene's Test	Adjusted Significance
1	To see if the two age groups process the words not know until age 5 differently (lexically, sublexically) and thus have different first-order neighbourhood density effects	Impact of age group (younger, older) on the repetition accuracy for the set of words with different first-order (high, low) neighbourhood densities	$p < .001$	$p < .01$
2	To see if the two age groups process the pseudo-words the same (sublexically) and thus have the same first-order neighbourhood density effects	Impact of age group (younger, older) on the repetition accuracy of pseudo-words with different first-order (high, low) neighbourhood densities	$p < .001$	$p < .01$
3	To see if word/non-word status affects the processing of phone strings with the same first-order neighbourhood densities	Impact of age group (younger, older) on the repetition accuracy of phone strings with different first-order (high, low) neighbourhood densities	$p < .001$	$p < .01$
4	To see if the two age groups process the words not known until age 5 differently (lexically, sublexically) and thus have different second-order neighbourhood density effects	Impact of age group (younger, older) on the repetition accuracy for the set of words with different second-order neighbourhood densities (HH, HL, LH, LL)	$p < .001$	$p < .01$
5	To see if the two age groups process the pseudo-words the same (sublexically) and thus have the same second-order neighbourhood density effects	Impact of age group (younger, older) on the repetition accuracy of pseudo-words with different second-order neighbourhood densities (HH, HL, LH, LL)	$p < .001$	$p < .01$
6	To see if word/non-word status affects the processing of phone strings with the same second-order neighbourhood densities	Impact of age group (younger, older) of the repetition accuracy on phone strings with different second-order neighbourhood densities (HH, HL, LH, LL)	$p < .001$ for all except the HH set	$p < .01$ for all except the HH set

6.3.5.1 **First-Order Neighbourhood Density**

6.3.5.1.1 Comparison of high and low first-order neighbourhood density phone strings within words and pseudo-words

Table 6-3 shows the descriptive statistics for the repetition accuracy of children under and over age 5 on words and pseudo-words with high and low first-order neighbourhood densities. Analysis was approached in a similar way to Comparison One (section 6.3.4): here two-way, between-groups analyses of variance were conducted for: 1) words not known until age 5, and 2) pseudo-words, to see if first-order neighbourhood density effects exists within words and pseudo-words. The goals and the results of Levene's test on these analysis are shown in Row 1 and 2 of Table 6-12.

For both the analyses of variance within words and pseudo-words, no significant interaction was found between age and first-order neighbourhood density, indicating that the first-order neighbourhood density of the words not known until age 5, and pseudo-words had no effect on the word repetition accuracies of both younger and older children (Table 6-14). There was also no main effect of first-order neighbourhood density. However there was a main effect of age in both comparisons. For the analysis of variance on words not known until age 5, the older age group (*M* = .872, *SD* = .334) was more accurate than the younger age group (*M* = .800, *SD* = .401). The same results were observed for the analysis of variance on the pseudo-words, where the older age group (*M* = .852, *SD* = .355) was more accurate than the younger age group (*M* = .727, *SD* = .446).

Table 6-13. *Descriptive statistics for the repetition accuracy of high and low first-order neighbours in children under and over 5 for words and pseudo-words.*

	Age	**First-order Neighbours**	***N***	***M***	***SD***
Word	Under 5	High	180	.822	.383
		Low	180	.778	.417
	Over 5	High	192	.849	.359
		Low	192	.896	.306
Pseudo-word	Under 5	High	150	.713	.454
		Low	180	.739	.441
	Over 5	High	160	.863	.346
		Low	192	.844	.364

Table 6-14. *Results from two-way between-groups analysis of variance for the factors first-order neighbourhood density and age in words not known until age 5 and pseudo-words. Those marked with an asterisk were significant (a p of < .01 was needed for significance).*

	Factors	***df***	***F***	***p***	**Partial eta squared**
Word	First-Order Neighbourhood Density and Age Interaction	(1, 743)	2.868	.091	.004
	Main Effect of First-Order Neighbourhood Density	(1, 743)	.002	.964	< .001
	Main Effect of Age	(1, 743)	7.209	.007*	.010
Pseudo-word	First-Order Neighbourhood Density and Age Interaction	(1, 681)	.512	.474	.001
	Main Effect of First-Order Neighbourhood Density	(1, 681)	.012	.912	< .001
	Main Effect of Age	(1, 681)	16.844	< .001*	.024

6.3.5.1.2 Comparison of high and low first-order neighbourhood density phone strings between words and pseudo-words

To see whether word/non-word status affects the processing of phone strings with the same first-order neighbourhood densities, a two-way, between-groups analysis of variance was conducted. The analysis of variance assessed the impact of two age groups (younger, older) on participants' repetition accuracy on phone strings (words not known until age 5 and pseudo-words) with different first-order (high, low) neighbourhood densities (results of Levene's test shown in Row 3 of Table 6-12).

As with the comparison between words known at age 3 and non-words, only a main effect of age was found between words not known until age 5 and pseudo-words for both high and low first-order neighbourhood densities, where the older age group were more accurate than the younger age group in both cases (Table 6-15).

Table 6-15. *Results from two-way between-groups analysis of variance for the factors high and low first-order neighbourhood density and age between words not known until age 5 and pseudo-words. Those marked with an asterisk were significant or approached significance (a p of < .01 was needed for significance).*

First-Order Neighbourhood Density	**Factors**	***df***	***F***	***p***	**Partial eta squared**
High	First-Order Neighbourhood Density and Age Interaction	(1, 681)	4.267	.039*	.006
	Main Effect of First-Order Neighbourhood Density	(1, 681)	2.588	.108	.004
	Main Effect of Age	(1, 681)	8.808	.003*	.013
Low	First-Order Neighbourhood Density and Age Interaction	(1, 743)	.055	.815	< .001
	Main Effect of First-Order Neighbourhood Density	(1, 743)	2.608	.107	.004
	Main Effect of Age	(1, 743)	15.661	< .001*	.021

However, the age and high first-order neighbourhood density interaction also approached significance. Figure 6-3 shows the interaction effect present between words not known until age 5 and pseudo-words with high first-order neighbourhood density. It appears that the repetition accuracy for children in the older age group was similar across words and pseudo-words with high first-order neighbourhood density, however the younger age group appears to perform better in the word set than the pseudo-word set.

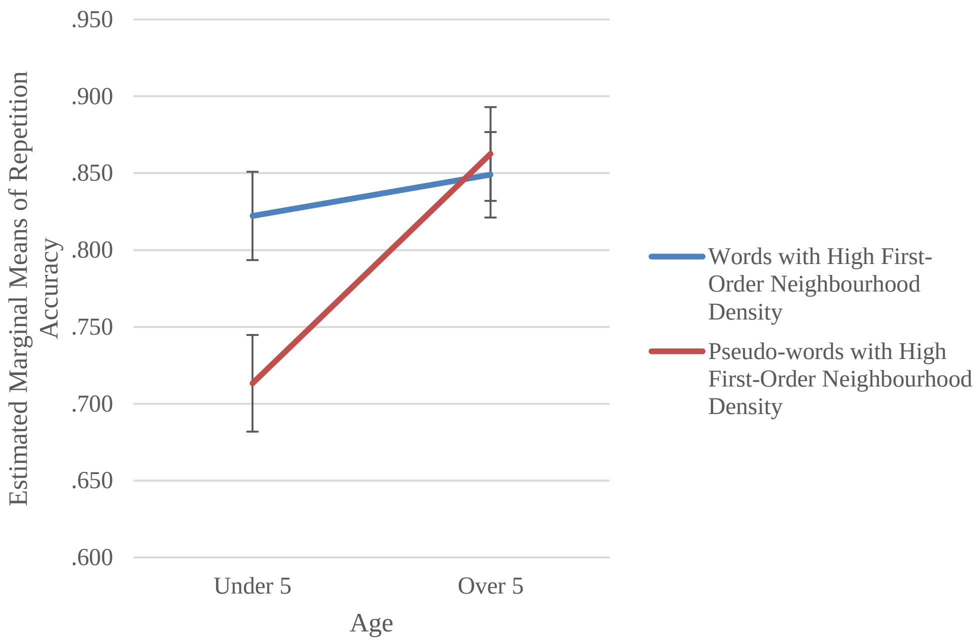

Figure 6-3. Plot illustrating the estimated marginal means of repetition accuracy with words and pseudo-words with high first-order neighbourhood density across ages. Error bars indicate standard errors.

6.3.5.2 **Second-Order Neighbourhood Density**

6.3.5.2.1 Comparison of HH, HL, LH, and LL within words and pseudo-words

Table 6-16 shows the descriptive statistics for the repetition accuracy of children under and over age 5 on words not known until age 5 and pseudo-words in the different second-order neighbourhood densities groups (HH, HL, LH, LL). Two two-way between-groups analysis of variance were conducted as described in Row 4 and 5 of Table 6-12.

For the analysis of variance on the words not known until age 5, no significant interaction was found between age and second-order neighbourhood density, indicating that the second-order neighbourhood density of the words not known until age 5 had no effect on the repetition accuracies of both younger and older children (Table 6-17). The main effect of second-order neighbourhood density approached significance. *Post hoc* tests using the Bonferroni correction indicated that there was a significant difference between LH (*M* = .780, *SD* = .416) and LL pseudo-words (*M* = .898, *SD* = .304), *p* = .011. A main effect of age was also found, where the older age group (*M* = .872, *SD* = .334) was more accurate than the younger age group (*M* = .800, *SD* = .401).

For the analysis of variance on the pseudo-words, no main effect of second-order neighbourhood density was found (Table 6-17). However, there was a significant effect of age, where the older age group (*M* = .852, *SD* = .355) was more accurate than the younger age group (*M* = .727, *SD* = .446). The interaction effect between age and second-order neighbourhood density approached significance so a simple effects analysis was conducted to explore the interaction effect (two one-way analysis of variance of second-order neighbourhood density effect on children under and over 5). A simple effects analysis was conducted here because there are more than are four groups of pseudo-words that need to be compared (HH, HL, LH, LL) against two age groups (younger, older). The interaction effect between the younger age group's repetition accuracy with the different neighbourhood sets was not significant, F (3, 329) = 2.605, p = .052. Similarly, no interaction effect was found between the older age group and the repetition accuracy of phone string sets with different neighbourhood densities, F (3, 351) = .640, p = .590.

Table 6-16. *Descriptive statistics for the repetition accuracy of second-order neighbourhood groups (HH, HL, LH, LL) in children under and over 5 for words and pseudo-words.*

	Age	**Second-order Neighbours**	***N***	***M***	***SD***
Word	Under 5	HH	90	.833	.375
		HL	90	.811	.394
		LH	90	.744	.439
		LL	90	.811	.394
	Over 5	HH	96	.844	.365
		HL	96	.854	.355
		LH	96	.812	.392
		LL	96	.979	.144
Pseudo-word	Under 5	HH	75	.773	.422
		HL	75	.653	.479
		LH	90	.667	.474
		LL	90	.811	.394
	Over 5	HH	80	.850	.359
		HL	80	.875	.333
		LH	96	.875	.333
		LL	96	.813	.392

Table 6-17. *Results from two-way between-groups analysis of variance for the factors second-order neighbourhood density and age in words not known until age 5 and pseudo-words. Those marked with an asterisk were significant or approached significance (a p of < .01 was needed for significance).*

	Factors	***df***	***F***	***p***	**Partial eta squared**
Word	Second-Order Neighbourhood Density and Age Interaction	(1, 743)	1.607	.186	.007
	Main Effect of Second-Order Neighbourhood Density	(1, 743)	3.162	.024*	.013
	Main Effect of Age	(1, 743)	7.284	.007*	.010
Pseudo-word	Second-Order Neighbourhood Density and Age Interaction	(1, 681)	3.088	.027*	.014
	Main Effect of Second-Order Neighbourhood Density	(1, 681)	.692	.557	.003
	Main Effect of Age	(1, 681)	17.007	< .001*	.025

6.3.5.2.2 Comparison of HH, HL, LH, and LL between words and pseudo-words

To see if word/non-word status affects the processing of phone strings with the same neighbourhood densities, four two-way between-groups analysis of variance were conducted. The goal and the results of Levene's test for these are in Row 6 of Table 6-12. As for Comparison One, HH, HL, LH and LL words were compared with their pseudo-word counterparts.

Only a main effect of age was found between words not known until age 5 and pseudo-words in the HL and LH second-order neighbourhood density category (Table 6-18). However, it should be noted that the LL sets also approached significance, showing a possible second-order neighbourhood density effect. For all the sets that were significant, the older age group was more accurate than the younger age group.

Table 6-18. *Results from four two-way between-groups analyses of variance for the different second-order neighbourhood density groups (HH, HL, LH and LL) and age between words not known until age 5 and pseudo-words. Those marked with an asterisk were significant or approached significance (a p of < .01 was needed for significance for the HL, LH and LL sets).*

Second-Order Neighbourhood Density	**Factors**	***df***	***F***	***p***	**Partial eta squared**
HH	Second-Order Neighbourhood Density and Age Interaction	(1, 340)	.644	.423	.002
	Main Effect of Second-Order Neighbourhood Density	(1, 340)	.424	.515	.001
	Main Effect of Age	(1, 340)	1.113	.423	.003
HL	Second-Order Neighbourhood Density and Age Interaction	(1, 340)	4.409	.036*	.013
	Main Effect of Second-Order Neighbourhood Density	(1, 340)	2.592	.108	.008
	Main Effect of Age	(1, 340)	9.685	.002*	.028
LH	Second-Order Neighbourhood Density and Age Interaction	(1, 371)	2.702	.101	.007
	Main Effect of Second-Order Neighbourhood Density	(1, 371)	.032	.858	< .001
	Main Effect of Age	(1, 371)	10.489	.001*	.028
LL	Second-Order Neighbourhood Density and Age Interaction	(1, 371)	5.376	.021*	.014
	Main Effect of Second-Order Neighbourhood Density	(1, 371)	5.376	.021*	.014
	Main Effect of Age	(1, 371)	5.557	.019*	.015

For both the HL and LL set it can be seen that their second-order neighbourhood density and age interaction effect approached significance. Additionally, the main effect of second-order neighbourhood density in the LL set also approached significance. Figure 6-4 and Figure 6-5 shows the interaction effects present between words not known until age 5 and pseudo-words for the HL and LL neighbourhood densities. For both sets it can be seen that the repetition accuracy of children in the younger age group is similar for words and pseudo-words, however, for the older age group, there is a clear difference with pseudo-words being produced less accurately than the words.

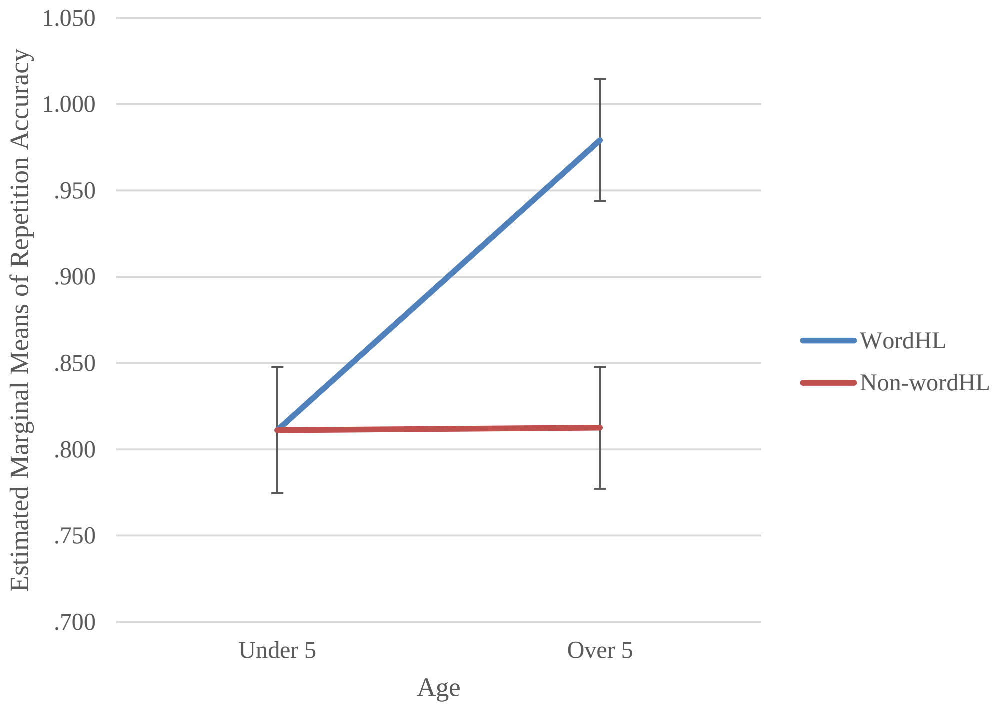

Figure 6-4. Plot showing the estimated marginal means of repetition accuracy with words and pseudo-words (non-words) with high first- and low second-order neighbourhood density across ages. Error bars indicate standard errors.

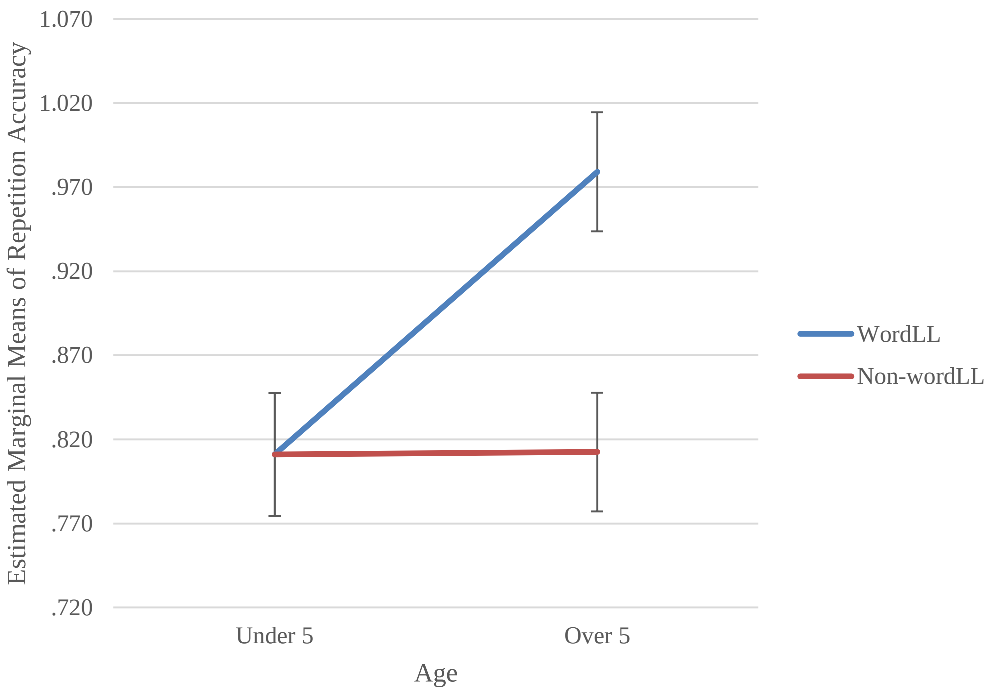

Figure 6-5. Plot showing the estimated marginal means of repetition accuracy with words and pseudo-words (non-words) with low first- and second-order neighbourhood density across ages. Error bars indicate standard errors.

For the main effect of second-order neighbourhood density, the LL words (M = .898, SD = .304) were produced more accurately across ages compared to the LL pseudo-words (M = .812, SD = .392).

6.4 Discussion

6.4.1 *Summary of Findings*

This experiment used the stimuli obtained from the computational analysis in Chapter 5 to test children's processing of words and non-words (phone strings that are not acquired into the lexicon by the individual) to see if there are processing differences. Based on the Generative Acquisition Hypothesis Processing Shift Model, known words are considered to be processed lexically such that a word with a high number of neighbours will hinder its own processing as there is lateral inhibition between the target word and its neighbours. This means a word with a high number of neighbours will be produced less accurately than a word with a low number of neighbours. Non-words on the other hand are processed sublexically so the effects of neighbourhood density are the opposite of those found in word processing. It was predicted that non-words with a high number of neighbours would be produced more accurately than a non-word with a low number of neighbours, as the neighbours of the non-word reinforce the way the non-word is produced.

In the experiment, factors of age, first-, and second-order neighbourhood density were investigated. Age is important as it indicates how many words a child has acquired in their vocabulary which will influence whether they will perceive a phone string as a word or a non-word, and the corresponding neighbourhood density statistics for that phone string.

It was hypothesised that for words known at age 3, all the participants would process these words lexically as they should all have acquired these words into their lexicon. Therefore words with high first- and second-order neighbourhood density should be processed less accurately. On the other hand, for words not known until age 5, only children 5 and above will treat them as words as only they have acquired them in the lexicon. Children under age 5 were therefore predicted to process these words sublexically (as non-words) so the words with high first- and second-order neighbourhood density should be processed more accurately (a reversed effect compared to children 5 and above).

Finally, for the set of pseudo-words, it was predicted that all the participants would treat them as non-words so processing would be sublexical. Thus, pseudo-words with high first- and second-order neighbourhood density would be processed more accurately than pseudo-words with low first-order and second-order neighbourhood density.

The processing of a phone string (lexically or sublexically) determines whether there would be any neighbourhood density or age main effects, as well as whether any interaction effects between these two factors will occur. Table 6-19 and Table 6-20 summarizes the predictions made for the different phone string sets that were examined in the analyses.

Table 6-19. *Predictions about which factors should have significant effects when repetition accuracy was compared between words known at age 3 and non-words (including words not known until age 5).*

Factors	**Comparison of HH, HL, LH, and LL within Word and Non-word**		**Comparison of HH, HL, LH, and LL between Word and Non-word**
	Word	**Non-word**	
Neighbourhood Density and Age Interaction	Not significant	Significant	Significant
Main Effect of Neighbourhood Density	Significant	Significant	Significant
Main Effect of Age	Not Significant	Significant	Significant

Table 6-20. *Predictions about which factors should have significant effects when repetition accuracy was compared between words not known until age 5 and pseudo-words.*

Factors	**Comparison of HH, HL, LH, and LL within Word and Pseudo-word**		**Comparison of HH, HL, LH, and LL between Word and Pseudo-word**
	Word	**Pseudo-word**	
Neighbourhood Density and Age Interaction	Significant	Not significant	Significant
Main Effect of Neighbourhood Density	Not Significant	Significant	Significant
Main Effect of Age	Significant	Not Significant	Significant

The investigation of second-order neighbourhood density effects is important, as the lexicon is considered to be built up based on connections between these remote words (connectionist models). Therefore second-order neighbourhood density should also affect the way words and non-words are processed as first-order neighbours would.

The results from the experiment were examined to see whether they supported the Generative Acquisition Hypothesis Processing Shift Model's predictions about the spoken repetition accuracy across ages and stimulus material sets. Summary of the results are presented in Table 6-21 and Table 6-22. Those cells in the tables that match or partially match the predictions made are coloured green and grey respectively. When a cell partially matches the predictions, this means there was a significant effect for a specific group of phone strings, e.g. significance for phone strings with low first-order neighbourhood densities but not with high first-order neighbourhood densities. As a significant effect was still found for a specific set, these are argued to have partially matched the predictions. In the following sections, the results from these tables are evaluated against the Generative Acquisition Hypothesis Processing Shift Model's predictions, and explanations are made on the unexpected findings that arose from the results.

Table 6-21. *Results from the experiment showing significant and non-significant effects when repetition accuracy was compared in words known at age 3 and non-words (including words not known until age 5). Cells in green indicate that the statistics for that entry match the predictions and those in red indicate that the statistics of that entry do not match the predictions. Cells in grey are those that partially match the predictions.*

Factors	**Comparison of HH, HL, LH, and LL within Word and Non-word**		**Comparison of HH, HL, LH, and LL between Word and Non-word**
	Word	**Non-word**	
Neighbourhood Density and Age Interaction	Not significant	Not Significant	Significant for Low First-Order Neighbourhood Density and Age Interaction, also for LL Second-Order Neighbourhood Density and Age Interaction
Main Effect of Neighbourhood Density	Not Significant	Significant only for Second-Order Neighbourhood Density	Not Significant
Main Effect of Age	Not Significant	Significant	Significant for all except LL phone strings

Table 6-22. *Results from the experiment showing significant and non-significant effects when repetition accuracy was compared in words not known until age 5 and pseudo-words. Cells in green indicate that the statistics for that entry match the predictions and those in red indicate that the statistics of that entry do not match the predictions. Cells in grey are those that partially match the predictions.*

Factors	**Comparison of HH, HL, LH, and LL within Word and Pseudo-word**		**Comparison of HH, HL, LH, and LL between Word and Pseudo-word**
	Word	**Pseudo-word**	
Neighbourhood Density and Age Interaction	Not Significant	Not Significant (Significance found for Second-Order Neighbourhood Density and Age Interaction but not in follow up simple effects analysis)	Significant for High First-Order Neighbourhood Density and Age Interaction also for HL and LL Second-Order Neighbourhood Density and Age Interaction
Main Effect of Neighbourhood Density	Significant only for Second-Order Neighbourhood Density	Not Significant	Significant only for LL Second-Order Neighbourhood Density
Main Effect of Age	Significant	Significant	Significant for all except HH phone strings

6.4.2 ***Evaluation of the Generative Acquisition Hypothesis Processing Shift Model***

The main argument proposed by the generative acquisition hypothesis shift model is that words are predicted to be processed lexically and non-words sublexically, and consequently neighbourhood density would have different effects based on this. High neighbourhood density is predicted to inhibit word processing but is predicted to facilitate non-word processing. Therefore, for words it is predicted that LL words would be the most accurate, followed by LH, HL and HH words. On the other hand, for non-words it is predicted that HH non-words would be the most accurate followed by HL, LH and LL non-words. These predictions can be tested by looking at the patterns seen across HH, HL, LH and LL phone strings for the three material sets used in the experiment.

6.4.2.1 **Words known at age 3**

Firstly, for words known at age 3, both age groups will process these items lexically, therefore there should be no significant word repetition accuracy differences between the age groups. It was expected from the predictions made that low neighbourhood density will facilitate processing.

The results of the analyses showed that there were no interaction effects between age group and first-order neighbourhood density of words, nor any interactions between age group and second-order neighbourhood density of words, thus supporting the hypothesis. Neither was there a main effect of age, as hypothesised. These results thus support the idea from the Generative Acquisition Hypothesis Processing Shift Model that known words are processed in the same way.

However, no main effects were found for neighbourhood density, which should have been significant. One explanation as to why no main effects of first- and second-order neighbourhood density were found could be because of the stability of words known at age 3. Elman (1993) proposed that as individuals grow, their lexicons develop and become more stable. Thus, early-acquired words should be better grounded in the lexicon than later-acquired words. Studies have supported this idea by showing reading and naming advantages for words acquired earlier in development compared to words acquired later in development (Ellis & Morrison, 1998; Morrison & Ellis, 1995). These ideas help to explain why in the current experiment no neighbourhood density effects were found for words known at age 3. It is possible that as words known at age 3 are words which were acquired around the time of the vocabulary spurt, they are better represented in the lexicon compared to words that are acquired later and then added into the lexicon.

6.4.2.2 **Pseudo-words**

For the set of pseudo-words, since neither age group would ever acquire this set of phone strings into their lexicon, they should always be processed sublexically, as proposed by the Generative Acquisition Hypothesis Processing Shift Model. First- and second-order neighbourhood density effects were therefore predicted to occur, where non-words with a high number of first- and second-order neighbours would be produced more accurately than those with a low number of first- and second-order neighbours.

The results from the analyses demonstrated a second-order neighbourhood density and age interaction, however, follow-up simple effects analysis did not reveal any age group effects on the different neighbourhood density sets. The results of the analyses therefore support the hypothesis made by the model which predicted that there should be no difference between the two age groups because they should both be processing the pseudo-words sublexically.

However, when looking at the main effect of neighbourhood density alone, no clear first- or second-order neighbourhood density effects were found, thus it can be argued that first- and second neighbourhood density of pseudo-words has no effect on word repetition accuracy, which rejects the hypothesis proposed by the model. This shows neighbourhood density effects may not be as strong as anticipated for pseudo-words.

The Generative Acquisition Hypothesis Processing Shift Model hypothesised that there should be no effect by age group as both groups should process the pseudo-words sublexically, however, a main effect of age was found, where the older age group were more accurate than the younger age group. This rejects the hypothesis proposed.

As all the stimuli here were treated as non-words for all the children tested, there should not be an age effect on performance. It therefore appears that there are other factors that are not considered here that contribute to better performance in the older age groups, such as improved concentration, more developed cognitive skills (Davis & D'Amato, 2010) and phonological systems (Berry & Eisenson, 1956; Grunwell, 1982), higher phoneme awareness and more practice in phone string repetition.

6.4.2.3 **Conclusion One**

The results for both the words and the pseudo-words indicated there were no neighbourhood density effects on repetition accuracy, which rejects the model's ideas that lexical and sublexical processing are affected by neighbourhood density. It thus appears that the effects of neighbourhood density are not as influential in phone string processing as predicted and shown in past studies on neighbourhood density effects. It is argued that words known at age 3 may not be affected by neighbourhood density, as these words are well grounded into the lexicon and are less likely to be affected by usage factors. On the other hand, for pseudo-words it is argued that the effects of neighbourhood density may not be as strong as is expected to be seen in word processing, thus for the stimuli used here there may not have been enough statistical power to demonstrate this effect.

To determine if the argument regarding words known at age 3 being well grounded and therefore not have neighbourhood density effects is correct, it is possible to look at the words not known until age 5 and check for neighbourhood density effects. For the words not known until age 5, only the older age group will see these as words, whereas the younger age group will see them as non-words, therefore, when looking at the results of neighbourhood density on this word set, the factor of age would need to be considered.

Similarly, to determine whether the argument about pseudo-words not having as strong neighbourhood density effects as words is correct, it is possible to look at the results from the non-word set (collapsing words not known until age 5 and pseudo-words). For the non-word set, children in the younger age group should view this set as non-words and process them sublexically, whereas the older age group will process some words lexically and others sublexically. Therefore it is predicted that there should be a neighbourhood density and age interaction.

6.4.2.4 **Words not known until age 5**

The words not known until age 5 are only words for the older age group. They constitute non-words for the younger age group as the phone strings have not yet been acquired into their lexicon. As illustrated by the Generative Acquisition Hypothesis Processing Shift Model, these words are not yet acquired into the lexicon because they have not had enough word repetition or contextual representation. As a result of the word/non-word status of these phone strings, which is dependent on age, it was hypothesised by the model that words with high first- and second-order neighbourhood density would hinder word repetition accuracy in the older age group, as they are processing the words lexically. On the other hand, for the younger age group this would aid word repetition, as they process the words sublexically (as non-words).

The results of the analyses did not reveal any interactions between age group, first- and second-order neighbourhood density of words, therefore rejecting the hypothesis proposed. It thus seems that the age groups are not processing the words not known until age 5 as differently as expected. It may be possible that although the younger age group has not acquired these words into their lexicon, they may be familiar with some of them (having heard them in speech spoken by adults). Yet, the frequency of occurrence for these words may not be high enough for them to pass the threshold requirement for word acquisition, so they are on the borderline concerning word/non-word status. This helps to explain why the differences between the two age groups, along with neighbourhood density effects, are not as prominent as expected.

However, although there was no significant interaction effect, there was a significant main effect of second-order neighbourhood density and a main effect of age. These are discussed subsequently.

The Generative Acquisition Hypothesis Processing Shift Model predicted that there should be no main effect of neighbourhood density for words not known until age 5, because the younger group will process these words sublexically and the older age group would process them lexically, thus cancelling out the effects of neighbourhood density. This hypothesis is supported in that no first-order neighbourhood density effect was found, however, an unexpected main effect of second-order neighbourhood density was found.

Post hoc tests indicated a significant difference between LH and LL words known only at age 5 and above. This could mean that words with a low number of first- and second-order neighbours are more likely to be influenced by their extended connections because they do not have enough immediate lexical connections that can influence processing.

Here, LL words were produced more accurately than LH words. As it was hypothesised that no neighbourhood density effect should be found, it is unclear why a significant difference was found between LH and LL words. If the assumption that the younger age group is treating some of the phone strings in the word set as words, it could be then argued that the LL phone strings were produced more accurately because there was less interference in the lexicon due to a lower number of lexical links in the form of word neighbours. This supports the prediction made by the Generative Acquisition Hypothesis Processing Shift Model that words with low neighbourhood density would facilitate lexical processing.

The Generative Acquisition Hypothesis Processing Shift Model predicted that there should be a main effect of age, as the younger group should process the words sublexically and the older group should process it lexically. A main effect of age was found for words, where the older age group was more accurate in the repetition task than the younger age group. This supports the hypothesis proposed by the model.

However, as there were no interaction effects between age and neighbourhood density factors as described in the beginning of this section, it is difficult to determine whether the main effects of age found are unquestionably a result of differences in processing. Other factors such as better concentration and more developed cognitive skills in the older age group could also account for the findings obtained. Thus the results here are inconclusive with respect to the validation of the Generative Acquisition Hypothesis Processing Shift Model.

6.4.2.5 **Non-word set (collapsing words not known until age 5 with pseudo-words)**

Similar to the results found for words not known age 5, there were no neighbourhood density and age interaction effects, which rejects the hypothesis proposed. However, there were the unexpected findings of a main effect of second-order neighbourhood density and a main effect of age.

A reason why no significant interaction effect was found in the non-word set could be because the older age group was processing some phone strings (the pseudo-words) in the non-word set sublexically, like the younger age group. This would have reduced the effects of neighbourhood density (essentially cancelling the effects out).

In the case of the main effect of second-order neighbourhood density, *post hoc* tests indicated a significant difference between LH and LL non-words, where LL non-words were produced accurately. This is the same result that arose in words not known until age 5.

From the results it thus appears that phone strings with a low number of first- and second-order neighbours are more likely to be affected by their extended connections. This possibly arises because the targets do not have enough immediate lexical connections in the lexicon to affect processing, thus a wider search through the lexicon is required to make connections between lexical items and the phone string that was presented. As the LL set was produced more accurately than the LH set, this shows that the fewer the number of lexical connections the more accurately an individual can produce that phone string, probably because there is less interference in the lexicon. The results here go against the ideas proposed by the model, as it was predicted that high neighbourhood density for non-words should facilitate processing, whereas here the opposite is observed. Therefore it may appear that regardless of word/non-word status, high neighbourhood density may cause interference in processing.

With respect to the main effect of age, it was found that the older group was more accurate than the younger group. The predictions from the model explained that there should be age effects because the older age group have the words not known until age 5 that are collapsed into this set of non-words. Children in the older age group therefore process some of the non-words lexically and some sublexically, whereas children in the younger age group would just process all the phone strings in the non-word set sublexically. Lexical processing should be more accurate than sublexical processing, as lexical processing matches words that actually exist in the lexicon and can be cross-verified. The results from the experiment support the model as there are significant differences between the two groups, which indicates that they are processing the non-words differently.

Although the main effect of age found does support ideas from the model, it could be argued that it may not necessarily be processing differences in the lexicon that caused these effects. Another reason as to why there was a main effect of age could be because of the task effect. As discussed in the procedure section, children's phonological systems develop over age, for example, children can only produce /k/ at around age 4 due to 'fronting' before this age (Berry & Eisenson, 1956; Grunwell, 1982). It is therefore possible that the age effect observed is an indicator of phonological development and accuracy rather than one that involves lexical processing.

6.4.2.6 **Conclusion Two**

The results of the repetition accuracy for words not known until age 5 did not show any interaction effects between age and neighbourhood density, which rejects the hypothesis from the Generative Acquisition Hypothesis Processing Shift Model that these two groups process the words differently (lexically and sublexically). Similarly, no interaction effects were found between age and neighbourhood density for the set of non-words, thus once again rejecting the ideas from the model that the two age groups process this set of phone strings differently.

It was argued that the younger age group may have acquired some of the words not known until age 5 hence why there were no differences between the two age groups. Should this assumption be correct, then the main second-order neighbourhood density effect found here will indicate that there are neighbourhood density effects present in word processing. In the case for the set of non-words it was argued that the older age group may process some phone strings lexically and some sublexically, which could be a reason why no effects were found as the processing effects cancelled each other out.

For both analyses, it was found that the LL phone strings were the most accurate. In the case of words not known until age 5, this supports the predictions made by the Generative Acquisition Hypothesis Processing Shift Model that low neighbourhood density words facilitate processing. On the other hand, for the set of non-words, LL phone strings were the most accurate, which goes against the predictions made by generative acquisition hypothesis processing shift the model that high neighbourhood density non-words facilitate processing. Should the assumption that children in the younger group have already acquired some of the words not known until age 5 to be correct, this explains the LL processing advantage. The reason for this is because both groups of children are processing the words not known until age 5 (which is collapsed into the non-word set) lexically, so low neighbourhood density will facilitate processing.

Nonetheless, for the two analyses only a second-order neighbourhood density effect was found and not a first-order neighbourhood density effect. This is an important finding as it shows that an extended network of connections between phone strings in the lexicon influences how phone strings are processed. The findings emphasise that research should not just look at immediate connections to a lexical item, such as first-order neighbours. These build on ideas from connectionist models about mass connectivity and how all words in the lexicon are connected. As the Generative Acquisition Hypothesis Processing Shift Model uses connectionist ideas, the main effect for second-order neighbourhood density therefore supports the basis of this model that all words known in the lexicon are connected and influence one another.

As here it is assumed that children in the younger age group have acquired the words not known until age 5 as well, like the older age group, it is possible to determine whether word/non-word status has an effect on processing by comparing the repetition accuracies of these words against the pseudo-words. Lexical processing should be more accurate than sublexical processing, as lexical processing matches words that actually exist in the lexicon and can be cross-verified sublexically. Whereas sublexical processing induces the acquisition of a new phone string not in the lexicon. The next section discusses the results of this comparison and uses it to evaluate the Generative Acquisition Hypothesis Processing Shift Model.

6.4.2.7 Comparing words not known until age 5 and pseudo-words

Based on the assumption that both age groups know the words from this word set, it was predicted that neighbourhood density effects for the word and pseudo-word sets would be different. For the word set, high neighbourhood density is predicted to inhibit processing whereas for the pseudo-words this will facilitate processing.

Analyses between words and pseudo-words showed a significant high first-order neighbourhood density and age interaction. Also significant interaction effects were found for the HL set and age, and the LL set and age. Furthermore a significant main effect was found for the LL set.

For the interaction effect between high first-order neighbourhood density and age, it was found that the younger age group was more accurate with the words than the pseudo-words with high first-order neighbourhood density. The older age group on the other hand performed similarly for both words and pseudo-words, which goes against the hypothesis that they are processing words and non-words differently. As with the HL and LL interactions with age, the results showed that the older age group produced pseudo-words less accurately than the words.

It is predicted by the model that words and pseudo-words are processed differently so there should be accuracy differences. Words should be processed more accurately than pseudo-words because the words exist in the lexicon and can be validated. As the results here are mixed, it appears that only certain phone string sets show a word processing advantage over non-word processing, and that such an advantage is determined by the age of the participants.

For the younger age group only high first-order neighbourhood density sets showed a difference, meaning that children in the younger age group find it easier to repeat high neighbourhood density words over non-words. On the other hand, for the older age group, only words with low second-order neighbourhood densities (HL and LL) were repeated more accurately than their pseudo-word counterparts. This shows that younger children are influenced by immediate connections (first-order neighbourhood density), whereas older children are influenced by connections beyond immediate lexical connections (second-order neighbourhood density).

A reason for the observed results could be that the older age group has a larger lexicon and therefore more connections between words, thus if immediate connections were to cause an effect then these effects will be very large due to the number of potential neighbours a word can have. Therefore, it is impractical for lexical processing to be affected by immediate connections, hence they are ignored. Following on from the idea that there are a large number of words in the lexicon, pseudo-words with low second-order neighbourhood densities would be less accurate. This is because they have the least number of connections with words in the lexicon and are therefore treated as a phone string that is unlikely to exist in English and thus less likely to be acquired.

The younger age group on the other hand have a smaller lexicon and are still in a process of lexical development and therefore will have very few extended connections. This is why first-order neighbourhood density effects are present in the younger children and not in the older children. Unlike the older age group, the younger age group would be at a point in development where they are likely to acquire as many new words as possible. As a pseudo-word with a high number of neighbours would not be seen as novel as one with a low number of neighbours, children would pay more attention to them (Hoover et al., 2010). Thus, the attentiveness of the children to this type of pseudo-word may have led to the effects discussed.

As well as the interactions discussed, there was a main effect of second-order neighbourhood density, where the LL words were produced more accurately across ages compared to the LL pseudo-words, independent of age group. The LL set was the only set of words that demonstrated this main effect, which shows that this set is different to the rest. It is possible that this effect was only present in phone strings with low first- and second-order neighbourhood density because they have the lowest number of lexical connections, so comparison of effects across words and non-words are more prominent.

6.4.3 *Limitations and General Discussion*

The findings from this experiment partially supported the hypothesis made by the Generative Acquisition Hypothesis Processing Shift Model as illustrated in Table 6-21 and Table 6-22, and discussed above. However there are a few problems that need to be considered.

Firstly, no significant main effects of neighbourhood density were found for the words known at age 3 and the pseudo-words, which rejects the hypothesis that first- and second-order neighbourhood density effects occur in word and non-word repetition. Secondly, no interaction effects were found between age group and neighbourhood density for words not known until age 5, nor for the non-word set, which shows that the two age groups do not process these sets differently. Therefore, it appears that the Generative Acquisition Hypothesis Processing Shift Model is not a complete explanation of word and non-word production differences.

In fact, it appears that the Generative Acquisition Hypothesis Processing Shift Model needs to take into account children's ages when trying to explain how they process and produce words, as there are clear age effects across both words and non-words for words known at age 3, words not known until age 5 and pseudo-words. The interaction effect between age group and neighbourhood density when looking at phone strings with the same neighbourhood densities across words not known until age 5 and pseudo-words discussed especially emphasises this point. This is because the two age groups are influenced by neighbourhood density differently.

To improve on the Generative Acquisition Hypothesis Processing Shift Model the age factor should not only be used to interpret whether a phone string is treated as a word or non-word, but it should be a factor itself that explains processing differences. It is possible that the older age group has more developed cognitive abilities (Davis & D'Amato, 2010) to deal with the processing of phone strings, and has more developed phonological systems than the younger age group (Berry & Eisenson, 1956; Grunwell, 1982), hence there are consistent age effects across all the stimuli in the experiment.

Although the findings offer partly contradictory support for the Generative Acquisition Hypothesis Processing Shift Model, these results are interesting as they demonstrate the importance of second-order neighbourhood density as well as first-order neighbourhood density. This is demonstrated in the significant main effects of second-order neighbourhood density found in words not known until age 5 and also in the non-word set. One of the reasons why there are contradictory findings in the literature on neighbourhood density effects could be because studies have only focused on first-order neighbourhood densities. Therefore, it is important to extend research to look at the wider lexical network than to focus on immediate connections.

In summary, the findings from the experiment reported here showed that there are effects of age, whether a word is treated as a word or non-word (based on word age-of-acquisition data), and neighbourhood density. When words that are not known are acquired and enter the lexicon, the way they are processed changes from how they were processed when they were non-words. These findings therefore indicate the importance of the shift between words, words not yet known and pseudo-words in the mental lexicon.

Using these ideas it is possible to devise test materials to determine the vocabulary levels of individuals. To do this, individuals could be tested with the stimuli and depending on how they react to the words, the experimenter could identify whether they have acquired the word or not and use this to pinpoint their vocabulary levels based on the child corpus used. It is also possible to use these results as a basis for understanding how children with language difficulties find it difficult to process certain words.

One suggestion could be that these children experience problems in reorganising the lexicon when new words are acquired, therefore affecting the speed and accuracy of their word processing. Further studies into how children who experience language difficulties, and also children with English as a second language, process words and non-words would be useful in establishing what problems they face. More importantly, second language acquisition is interesting because it reapplies the Generative Acquisition Hypothesis Processing Shift Model but for a second language. As the same shifts from non-word to word occur when a second language is acquired, the same model should be applicable. In the next chapter, a study looking at bilingual children using the same procedure as the current experiment is designed, carried out and reported, in order to see if second language acquisition can also be predicted by the Generative Acquisition Hypothesis Processing Shift Model.

7 Chapter 7: Neighbourhood Density Effects in Word Production by English and Cantonese Monolingual and Bilingual Children

7.1 Introduction

The results from the computational analyses and experiments conducted so far illustrate the neighbourhood density changes that occur in words and non-words as a child develops and how they affect performance.

The Generative Acquisition Hypothesis Processing Shift Model proposed in Chapter 2 helped to rationalize how processing should differ across the different phone strings. Based on the type of processing that occurs (lexical for words, sub-lexical for non-words), neighbourhood density should have different effects. The model proposed that high neighbourhood density would inhibit lexical processing and facilitate sublexical processing, whereas low neighbourhood density would do the opposite.

Looking at children's repetition accuracy in the second experiment (Chapter 6), there were no significant interactions between age group and first- and second-order neighbourhood density on the repetition accuracy within any of the phone string sets. Thus, the predictions made by the model were not confirmed. However, a main effect of age occurred with all the stimuli, including both words and non-words, apart from the HH (for Comparison Two) and LL (for Comparison One) material. A main effect of second-order neighbourhood density was also found for the LL phone set for words not known until age 5 and the non-word set. This showed that neighbourhood density effects affect performance (second-order in particular).

The Generative Acquisition Hypothesis Processing Shift Model needs to account for age differences when children's word productions are considered. From the previous experiment it was concluded that age does not only affect the first- and second-order neighbourhood density properties of the words, but also age determines the cognitive skill level that affects children's word productions. This is an important factor to consider, as age should affect processing in ways other than determining whether a phone string has word or non-word status at a given stage in development.

Although some evidence has been provided to support the Generative Acquisition Hypothesis Processing Shift Model, so far only monolingual children's data has been assessed in the studies. Monolinguals were focused on in order to prevent second language variables from affecting the results. However studies in the literature have shown that the effects of neighbourhood density on word processing differ across monolinguals and bilinguals because of the different numbers of words in their lexicons (Jared & Kroll, 2001; Van Heuven et al., 1998). Therefore it is necessary to consider bilingual status when lexical processing is investigated.

From this perspective, a limitation in the second experiment (Chapter 6) was that its results only applied to English monolingual children. However, as the Generative Acquisition Hypothesis Processing Shift Model explains the changes in processing between a phone string that does not exist within the lexicon to becoming one that does exist within the lexicon, the model should also be applicable to second language acquisition. Thus, in this Chapter, a third experiment is reported. The aim was to investigate how the Generative Acquisition Hypothesis Processing Shift Model applies to bilingual children. First, literature is reviewed that provides the basis for predictions of what neighbourhood density effects occur in bilinguals. The literature review then looked at the phoneme inventories for the languages used by the bilingual group as these are pertinent to the predictions of the experiment.

7.2 Literature Review

In addition to the studies on neighbourhood density effects in monolingual children (as discussed in Chapter 2), there are also studies of such effects in bilinguals. In the present literature review, methods for obtaining neighbourhood density statistics across languages are discussed first, followed by experimental studies on how neighbourhood density affects bilinguals. The findings from these studies were used to propose two alternative model additions about language processing by bilinguals within the Generative Acquisition Hypothesis Processing Shift Model.

7.2.1 *Neighbourhood Density Calculations across Languages*

Motivated by similar considerations to those studies that have examined age effects on neighbourhood density statistics in monolingual children (discussed in Chapter 2), Duyck, Desmet, Verbeke, and Brysbaert (2004) wrote a program to determine neighbourhood density properties within languages (in particular English, Dutch, German and French) and to see how neighbourhood density differed across languages. The program allows users to ask for the neighbourhood size of words with a selected number of letters within a language. Their neighbourhood density calculations showed that words from different languages have different numbers of neighbours for words with a particular number of letters. For example it was shown that Dutch and German had more neighbours for 8-letter words compared to English and French.

The program also allowed users to input a target phone string and then select the language they are interested in. The program then gives an output with a list of properties of the phone string such as the number of neighbours that phone string has for the selected language. This makes it possible to calculate the number of neighbours an English word like ‘cat’ has in Dutch, German and French.

Duyck et al.'s (2004) program shows what word neighbours an English word has in Dutch, German and French. It could be used to select words that have a high number of neighbours in English, but a low number of neighbours in French or vice versa. Then the language-specific neighbourhood density properties could be investigated for their impact on word processing. For instance, a word set might be LL for an English monolingual and would affect processing accordingly. However, the words could be selected so that the LL English words were HH words in French. The question then is whether English-French bilinguals process the English words as LL by accessing their English lexicon or whether the HH French properties affect processing (showing that the two lexicons are not completely separate). These are important considerations when considering how bilinguals might process words. There are also differences across second languages because the phonetic structures of the languages leads to variation in numbers of neighbours that words have, as demonstrated by Duyck et al. (2004).

Vitevitch (2012) conducted a study that also considered the influences of neighbourhood densities in different languages. He looked at the phonological neighbours of words in English and Spanish, and across these languages. Based on a corpus analysis, he found that English words have few neighbours in Spanish and similarly, Spanish words had few neighbours in English. This study showed that although there may be cross-language neighbours, in the case of English and Spanish, they are rare. This shows that some languages can have word neighbourhood density properties that contrast with those of others. Therefore, it is important to consider what languages a bilingual knows and what cross-language neighbourhood density effects these languages are likely to lead to. With this information, it should then be possible to predict how neighbourhood density properties affect processing by bilinguals who speak these languages.

7.2.2 *Experimental Studies on Neighbourhood Density Effects in Bilinguals*

Studies have compared the effects of neighbourhood density on word processing in monolinguals and bilinguals. Van Heuven et al. (1998) used a progressive demasking and lexical decision task to determine the effects of orthographic neighbourhood density on word processing of Dutch-English bilinguals. For the progressive demasking task, a target word and a mask were presented in sequence. During the task, the presentation time of the word slowly increased and the time the mask was displayed decreased. Participants were asked to press a button as soon as they could identify the target word. After the button was pressed, they were asked to enter the word they believed they had seen. For the lexical decision task, English and Dutch words as well as a set of non-words were presented and participants were required to identify whether the phone string that was presented was a word (in English or Dutch) or a non-word.

It was found that English words with a large number of Dutch neighbours were responded to at a slower rate than English words with a small number of Dutch neighbours. This effect was only present in Dutch-English bilinguals and not in monolinguals. Therefore the findings demonstrate that neighbourhood density effects cross over between the languages known by an individual (a between language effect). One implication of this is that neighbourhood density statistics should be computed for all the languages an individual knows.

A study by Jared and Kroll (2001) looked at phonological neighbourhood density effects in English-French (dominant in English) and French-English (dominant in French) bilinguals. They required participants to name English words (first block of English). This was followed by a block where French words were named (filler block). After the filler block, a second block of English words was named (second block of English). For the English-French bilinguals, the words in the first block of English with French neighbours were named as quickly as words with no French neighbours. This showed that the English-French bilinguals did not activate their French lexicon when processing the English words. This could be interpreted as showing that the English and French lexicons are separate in these bilinguals. However, when the French-English bilinguals named words in the first block of English, they produced more errors for words with French neighbours than for the words with English neighbours. This showed that these bilinguals activated their French lexicon when processing English words (the opposite of what was found for reaction time in the English-French bilinguals). Furthermore, the results when words in the second block of English were named revealed that the English-French bilinguals who were fluent in French took longer to name words with French neighbours than those without French neighbours. This effect was not found in the first block of English words. Thus, the French filler block used between the two English blocks, activated these participants' French lexicons.

Based on these findings, it can be seen that neighbourhood density influences depend on the languages known by an individual, and that these effects depend on which language is dominant for the individual. Thus, in studies on bilinguals it is important to record which language dominates.

7.2.3 *Models of Language Processing for Bilinguals*

Based on the literature on neighbourhood density effects and their impact on language processing in bilinguals, two positions emerge. On the one hand it appears that there are between-language effects where the lexicon of a second language can affect the processing of the first language. This suggests that there are connections across the lexicons for the languages (Duyck et al., 2004; Van Heuven et al., 1998). On the other hand, other evidence shows that the lexicons of the first and second languages are independent and do not interfere with each other's processing (Jared & Kroll, 2001; Vitevitch, 2012).

Based on these two positions, two extensions to the model of language processing (Generative Acquisition Hypothesis Processing Shift Model) are made when applying it to bilinguals. The two extensions are the 'Extended Vocabulary

Model', which allows an interaction between the first and second language, and the 'Reduced Vocabulary Model', which proposes that the first and second languages are separate. These models are described below.

7.2.3.1 **The Extended Vocabulary Model**

The Extended Vocabulary Model proposes that bilinguals have a larger vocabulary compared to monolinguals as they acquire words from two different languages and insert them into a common lexicon. Therefore for a given word, a bilingual would have more potential word neighbours than would a monolingual.

Earlier chapters discussed how reorganisation occurs when new words are acquired. According to the Extended Vocabulary Model, the same reorganisations would occur when a word from a second language is acquired into the lexicon of a bilingual. This in turn should affect the way words are processed as bilinguals would have different numbers of neighbours for the same word compared to monolinguals.

For instance, 'egg' has 29 word neighbours in English. This is based on computations using the neighbourhood density calculator in Chapter 5. With the maximum 29 neighbours that an English monolingual speaker could have acquired, 'egg' would have a low neighbourhood density. However, it is possible that 'egg' also has word neighbours in other languages that would change the neighbourhood density estimates in bilingual children if the Extended Vocabulary Model is applicable. This would result in a bilingual child having more lexical links to the word 'egg' than a monolingual. The extra lexical links in bilinguals would cause reorganisation of the lexicon so that some words which would have been designated as LL words in monolinguals could be HH, HL or LH words in bilinguals. As the neighbourhood densities of the word depends on the languages the child knows, word processing would differ across monolinguals and bilinguals.

The Extended Vocabulary Model therefore predicts that all languages are stored in a single lexicon and words are connected via their shared phonological structure. The way individuals would identify which language a certain word is from could be based on other properties of the word, such as a language tag that categorizes which language a word belongs to (Green, 1998).

7.2.3.2 **The Reduced Vocabulary Model**

Jared and Kroll's (2001) and Vitevitch's (2012) experiments that investigated neighbourhood density effects in bilinguals imply that neighbourhood density effects are restricted to particular languages rather than shared across languages.

The Reduced Vocabulary Model therefore proposes that bilinguals have separate lexicons for the two languages that they know. As bilingual children have to spend time learning the two different languages, their vocabulary levels would be lower than those of monolingual children who speak one of the languages. Therefore, bilinguals would act like children who are phonologically delayed and treat some first language words that monolingual children of corresponding age know as non-words. The Reduced Vocabulary Model therefore predicts that bilinguals would process some words in a word repetition task sublexically (perceived as non-words) whereas monolingual children would process these words lexically (the latter group has acquired the words into their lexicon).

7.3 The Present Study

It was hypothesised that bilinguals would have different word neighbourhood properties from monolinguals in both first- and second-order neighbours, based on the research that has addressed neighbourhood density effects of words in bilinguals. The difference could occur because bilinguals have words that enter the lexicon from a different language (Extended Vocabulary Model) thus reorganising the number of neighbours words have. Alternatively, this could arise because bilinguals have a reduced vocabulary compared to monolinguals, as they have to share their time learning two languages (Reduced Vocabulary Model), therefore all words would have a comparatively low number of neighbours in the target language compared to monolinguals. Consequently, the performance on word processing tasks should differ between bilinguals and monolinguals because of the different neighbourhood density bilinguals have relative to monolinguals.

In order to examine the processing differences between monolinguals and bilinguals, the present experiment employed a group of bilingual children who were tested as in the experiment reported in Chapter 6. The performances on the phone string types were compared across language groups.

One possible way to assess the Reduced and Extended Vocabulary Models for processing differences between monolinguals and bilinguals would be to use neighbourhood density calculators to estimate the number of neighbours a target word has across languages (Duyck et al., 2004). For example, calculations could be made for the phone strings used in the spoken repetition test, to see how many Cantonese word neighbours these phone strings have. Neighbourhood density statistics could then be obtained for monolinguals and bilinguals, and any effects on repetition performance could be ascertained. This would make it possible to falsify or confirm the prediction of the Extended Vocabulary Model, as the model maintains that the bilinguals would have a higher number of neighbours for the same phone string compared to monolinguals.

However, there are no neighbourhood density calculators that can calculate cross-language neighbours for all languages (here between English and Cantonese). Thus other ways of examining the models are required.

The option taken here was to investigate the effects of language on spoken repetition performance for phone strings with different neighbourhood densities in a group of Cantonese monolingual children in addition to the Cantonese-English bilinguals and monolingual English children. The same spoken repetition test material was used with all three groups in order to see what differences occur between them. This way the bilingual group can be compared to the two monolinguals groups in order to identify any influences of knowing a second language on word processing.

In order to understand the cross language neighbourhood density effects between English and Cantonese (an effect that is predicted to occur by the Extended Vocabulary Model), it is necessary to consider the phonological differences between these two languages. The following section explores the phoneme inventories of English and Cantonese to see how they may affect neighbourhood density. Predictions about phone string processing differences between the three language groups, based on the two proposed models are then presented.

7.3.1 ***Phoneme Inventories of English and Cantonese***

English is a Germanic language, belonging to the Indo-European language family. Cantonese is a dialect of Chinese that belongs to the Sino-Tibetan language family. Therefore, the two languages have very different phonetic, phonotactic and prosodic properties (Chan & Li, 2000; Holm & Dodd, 1999; Meng, Zee, & Lee, 2007).

There are large differences between the number of vowels and consonants across English and Cantonese (Holm & Dodd, 1999). English has more instances of both phone types. There are only six consonants that are used in the final position for Cantonese (/t/, /k/, /p/, /m/, /n/, and /ŋ/) whereas there are 21 in English (/p/, /b/, /t/, /d/, /k/, /g/, /m/, /n/, /ŋ/, /θ/, /ð/, /f/, /v/, /s/, /z/, /ʃ/, /ʒ/, /ʧ/, /ʤ/, /l/, and /ɹ/). There are also some Cantonese phonemes that are not found in English, e.g. /p^h/, /t^h/, /k^h/, /ts^h/, and /ts/. Also it should be noted that Cantonese is a tonal language. These factors would influence the number of neighbours words have across these languages.

There are many more differences between the two languages than there are similarities. Consequently, it is unlikely that there are many word neighbours across the languages. This is an important consideration when the Extended Vocabulary Model is used to predict the repetition performance of bilinguals, as the model predicts that cross-over neighbours between the two languages affect the overall phone string neighbourhood density properties of the stimuli.

7.3.2 ***Predictions from the Extended Vocabulary Model***

Three language groups were tested in this experiment: English monolinguals, Cantonese-English bilinguals and Cantonese monolinguals. The same stimuli were used as in Chapter 6 and the same two comparisons between phone string sets were made: 1) between words known at age 3 and non-words (including those words not known until age 5), 2) words not known until age 5 and pseudo-words.

The Extended Vocabulary Model hypothesises that the two monolingual groups will only have their first language lexicons; Figure 7-1 shows that English monolinguals only have an English lexicon (yellow); Cantonese monolinguals only have a Cantonese lexicon (blue); as the Cantonese-English bilinguals know both languages, they have a shared English and Cantonese lexicon (green).

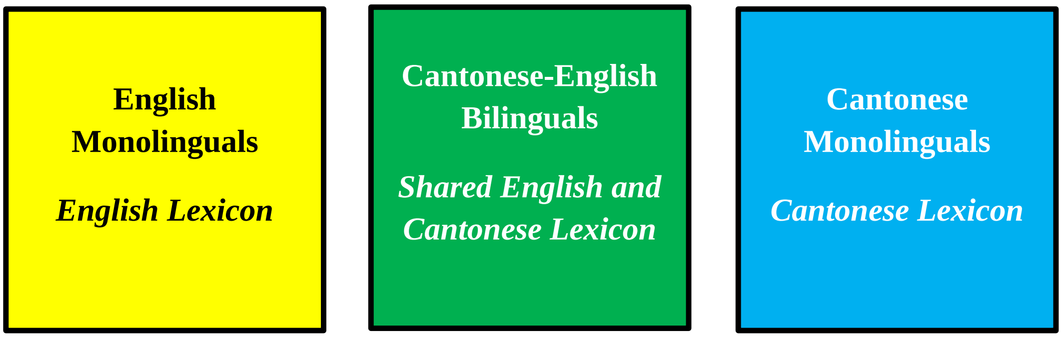

Figure 7-1. Diagram illustrating the lexicons that English monolinguals, Cantonese-English bilinguals and Cantonese monolinguals have.

The Extended Vocabulary Model therefore predicts that all three language groups should differ from each other on their repetition performance, because they have different words in their lexicons, which would lead to different neighbourhood density influences for the materials. Thus the neighbourhood density properties of the stimuli calculated for the experiment in Chapter 6 only apply to the English monolingual group.

It was predicted that there should be an interaction between language(s) known and first and second-order neighbourhood density in the spoken repetition task. Table 7-1 and Table 7-2 summarize these predictions for the two phone string set comparisons made in the study. From these tables it can be seen that there should be significant effects across all factors and comparisons, apart from a main effect of language on the pseudo-words. This is because the pseudo-words should not be acquired by any of the three language groups so they should always be treated as non-words and be processed sublexically (based on proposals from the Generative Acquisition Hypothesis Processing Shift Model).

However looking at the phoneme inventories of English and Cantonese in the previous section, it was shown that the two languages are very different and there are unlikely to be cross-over neighbourhood density effects. Therefore it can be argued that the Cantonese-English bilingual group would perform similarly to the English monolingual group if there was little influence of Cantonese on the processing of English words.

Table 7-1. *Predictions of which factors should have significant effects when repetition accuracy was compared between words known at age 3 and non-words (including words not known until age 5) across language groups.*

Factors	**Comparison of HH, HL, LH, and LL within Word and Non-word**		**Comparison of HH, HL, LH, and LL between Word and Non-word**
	Word	**Non-word**	
Language and Neighbourhood Density Interaction	Significant	Significant	Significant
Main Effect of Neighbourhood Density	Significant	Significant	Significant
Main Effect of Language	Significant	Significant	Significant

Table 7-2. *Predictions of which factors should have significant effects when repetition accuracy was compared between words not known until age 5 and pseudo-words across language groups.*

Factors	**Comparison of HH, HL, LH, and LL within Word and Pseudo-word**		**Comparison of HH, HL, LH, and LL between Word and Pseudo-word**
	Word	**Pseudo-word**	
Language and Neighbourhood Density Interaction	Significant	Significant	Significant
Main Effect of Neighbourhood Density	Significant	Significant	Significant
Main Effect of Language	Significant	Not Significant	Significant

7.3.3 ***Predictions from the Reduced Vocabulary Model***

The Extended Vocabulary Model proposed that bilinguals acquire words from their first and second languages and places them in the same lexicon, and thus cross-over neighbourhood density between the languages can occur. However, the Extended Vocabulary Model does not take into account the fact that the bilingual group may not have learned as many words in English as English monolinguals of the same age. This is because they have to spend their time learning their first and second languages.

The Reduced Vocabulary Model is different from the Extended Vocabulary Model because this model hypothesises that the bilingual group store their first and second languages in separate lexicons so that the two do not cross-over and interact.

As the English and Cantonese lexicons of a Cantonese-English bilingual do not interact, the Reduced Vocabulary Model hypothesises that word repetition performance should be affected by how much time a child spends on learning each language (as this would determine what words exists within the first and second language lexicons). It was hypothesised for this model that across the three groups, the English monolinguals would have spent the most time learning English compared to the other two groups, followed by the Cantonese-English bilinguals and finally the Cantonese monolinguals.

English monolinguals spend their time learning English so their lexicons should only consist of English words. The Cantonese-English bilinguals on the other hand have to split their learning time between English and Cantonese, thus the words that exist within their lexicons are determined by the child's exposure to each language. Finally, the Cantonese monolinguals should arguably only spend their time learning Cantonese so their lexicons should consist of Cantonese words only, therefore they would regard all English words as non-words.

As a result of the differences between the three language groups' lexicons, their repetition performance on the stimuli are predicted to be different. The English monolinguals were predicted to perform the best as they have spent the most time out of the three language groups in learning English. Hence they would have acquired more English words than the other two groups. It should be recalled that according to the Generative Acquisition Hypothesis Processing Shift Model, known words are processed lexically and are more accurate than non-words, which are processed sublexically. The high number of English words in the English monolingual group is why this group is predicted to have a processing advantage over the other two groups.

The Cantonese-English bilinguals' repetition accuracy was predicted to be worse than that of the English monolinguals but better than that of the Cantonese monolinguals because they spend less time than English monolinguals learning English (although more time than Cantonese monolinguals). As the bilingual group spends less time than the English monolinguals in learning English, it was predicted that the bilingual group would act like phonologically delayed English monolinguals.

The stimuli used consist of words known at age 3 and 5 which are drawn from the second computational analysis that used speech samples from CHILDES. As the speech samples are from American children, the age-of-acquisition properties of the words are not representative for bilinguals. As argued by the Reduced Vocabulary Model, bilinguals spend less time learning English, so they may acquire English words at a slower rate than English monolinguals. Thus, 3 year old bilinguals may not have acquired words known at age 3 by English monolinguals and will treat these stimuli as non-words. Therefore based on the predictions about bilinguals, these age-of-acquisition statistics of the words in the stimuli may not apply to the bilingual group. As the bilingual group is likely to have a smaller English lexicon, this means the neighbourhood density properties of words would also differ as a result of the words that exist within the lexicon. Due to this difference it is predicted that there will be language group and first- and second-neighbourhood density interactions in children's repetition accuracies.

The Cantonese monolinguals' repetition accuracy was predicted to be the worst out of the three language groups because Cantonese monolinguals should not have spent any time learning English and will treat all the phone string sets (words known at age 3 and 5 and pseudo-words) as non-words and would therefore process them all sublexically.

The predictions made by the Reduced Vocabulary Model in relation to language group and first- and second-neighbourhood density interactions and main effects are essentially the same as the Extended Vocabulary Model (Table 7-1 and Table 7-2). The only difference in the predictions made by the two models is that the Reduced Vocabulary Model considers language exposure as a factor that needs to be added to the model. The Reduced Vocabulary Model therefore predicts that the higher the exposure to English, the better the repetition accuracy.

7.3.3.1 **Assessing Time used in Language Learning**

The Reduced Vocabulary Model argues that language group processing differences are a result of the amount of time children in these groups spend learning their languages. In order to determine how much time the Cantonese-English bilingual children spent learning their two languages, a language questionnaire was devised (see section 7.5.2.2.2) to see whether there were any links between time spent on learning each language and their repetition performance.

To establish whether there was any variation in exposure to English and Cantonese in the Cantonese monolingual group, the language questionnaire was also administered to this group. The questionnaire scores allowed assessment of whether time spent learning English was related to word repetition performance of words with different first- and second-order neighbourhood densities. It is possible that Cantonese monolingual children have learned some English at school or through the media, which means that some English words would be known (although this would vary across children). Thus it is important to assess children's language exposure and to see whether there are correlations between language exposure and performance on phone string types with different neighbourhood densities. It was predicted that there would be a positive correlation between word repetition performance and amount of English exposure, as the more time spent learning English, the more likely the performance would approximate to that of English monolinguals.

A further feature of interest in this experiment was whether it is possible to determine how much time children spend in language learning by asking them directly rather than their parents. Experimental studies frequently ask parents to complete questionnaires about their child's language profiles (Chincotta & Underwood, 1998; Gutierrez-Clellen & Kreiter, 2003; Marchman, Martínez-Sussmann, & Dale, 2004). As it is increasingly important to consider children as thinkers and agents in their social world (Bell, 2007; Borgers, Leeuw, & Hox, 2000), it would help future experimental studies if children were confirmed as being able to provide accurate accounts of their language learning time. This would save time in experimental studies as the language questionnaire can be administered as part of the experiment on children instead of relying on parents to return copies of the questionnaire to the experimenter. Therefore, in order to assess whether this approach is plausible, language history questionnaires were administered to the children as well as their parents and the reliability between the two was assessed.

7.4 Experiment Three

This experiment aimed to look at the effects of first- and second-order neighbourhood densities for words and non-words known at ages 3 and 5, in English monolingual, Cantonese-English bilingual and Cantonese monolingual language groups. Children's repetition accuracy was the dependent variable.

Using the same method as Chapter 6, Cantonese-English bilingual and Cantonese monolingual children were tested and their repetition accuracy scores were analysed along with the dataset in Chapter 6. Thus the datasets available were Cantonese-English bilingual, Cantonese monolingual and English monolingual. Statistical tests were conducted to establish any differences between monolinguals' and bilinguals' stimulus repetition accuracy. The same two neighbourhood comparisons were made as in Experiment Two. These were: within and between words known at age 3 and non-words (including words not known until age 5, as these are treated as non-words by children under age 5); and between words not known until age 5 and pseudo-words.

A language history questionnaire was also administered to the Cantonese-English bilingual and Cantonese monolinguals children and parents in order to assess their exposure to English and Cantonese.

7.5 Method

7.5.1 ***Participants***

7.5.1.1 **Cantonese-English Bilinguals**

Twenty-two Cantonese-English bilingual children (10 males, 12 females) were recruited in London. Descriptive statistics about participants' time lived in the United Kingdom and their language exposure to English and Cantonese were calculated using the information from the parents' responses to the language history questionnaire (see section 7.5.2.2.2). Participants were classified as Cantonese-English bilinguals if they lived in the United Kingdom and had acquired Cantonese as their first language. The average percentage of time spent in the UK (time spent in the UK/age x 100) was 88.35% (*SD* = 22.66). Table 7-3 shows the average percent of their lives spent exposed to English and Cantonese at home, and English and Cantonese at school (cumulative exposure for each/age x 100).

Table 7-3. *Descriptive statistics for the Cantonese-English Bilinguals' English and Cantonese language exposures at home and in school.*

Language Exposure		***N***	***M***	***SD***
At Home	English	22	27.21%	18.97
	Cantonese	22	65.30%	26.85
In School	English	22	61.07%	16.56
	Cantonese	22	8.14%	11.29

7.5.1.2 **Cantonese Monolinguals**

Twenty-two Cantonese monolingual children (6 males, 16 females) were recruited from different schools across districts in Hong Kong. Participants were classified as Cantonese monolinguals if they lived in Hong Kong, had Cantonese as their first language and did not speak another language to their parents. None of the Cantonese monolinguals had spent any time in the UK. As with the bilingual group, the Cantonese monolinguals language exposure was calculated from the parent language history questionnaire responses (Table 7-4).

Table 7-4. *Descriptive statistics for the Cantonese monolinguals' English and Cantonese language exposures at home and in school.*

Language Exposure		***N***	***M***	***SD***
At Home	English	22	23.56%	20.83
	Cantonese	22	71.94%	21.38
In School	English	22	20.67%	17.76
	Cantonese	22	44.74%	17.71

7.5.1.3 **Combined Data**

There were 31 English monolingual participants (those whose data were reported in Chapter 6), 22 Cantonese-English bilinguals and 22 Cantonese monolinguals.

For the younger age group (under 5) there were 15 English monolinguals (age range 2 years and 9 months to 4 years and 7 months), 5 bilinguals (age range 4 years and 2 months to 4 years and 9 months) and 11 Cantonese monolinguals (age range 2 years and 9 months to 4 years and 10 months). For the older age group (over 5) there were 16 English monolinguals (age range 5 years and 2 months to 8 years and 10 months), 17 bilinguals (age range 5 years and 2 months to 12 years and 6 months) and 11 Cantonese monolinguals (age range 5 years to 11 years).

7.5.2 ***Procedure***

7.5.2.1 **BPVS and Repetition Task**

The procedure for the experiment was the same as that of Experiment Two (Chapter 6). Participants were first presented with the BPVS test to ensure that all the participants within each language group had comparable and age-appropriate scores when compared with the other members of their language group.

After the BPVS test, children performed the speech production repetition task where they had to repeat as accurately as possible the phone strings that they heard over headphones. Practice trials were presented until the children repeated three strings correctly. The test trials were then conducted.

Recordings of each child's responses in the repetition task were recorded and scored offline by the experimenter. To be scored 'correct' the whole phone string had to be spoken accurately, as in the second experiment (Chapter 6). However, here allowances were made for accent of the child. Cases where one phoneme was consistently pronounced as another throughout the experiment were allowed (e.g. different vowel forms). This was permitted to prevent any foreign-accented pronunciation affecting the results since the experiment was about lexical processing and not children's articulation of particular phonemes. This approach follows that used in previous research that has scored bilinguals' repetition accuracy (Armon-Lotem & Chiat, 2012; Gutiérrez-Clellen & Simon-Cereijido, 2010). The same experimenter scored all responses to ensure scoring consistency.

7.5.2.2 **Language History Questionnaire**

7.5.2.2.1 Methods in Assessing Bilingual's Language Exposure

Bilinguals have to divide their time for language development between their two languages, thus their exposure time to each language would not be comparable to a monolingual individual of the same age (Unsworth et al., 2011). Due to the reduced exposure time each language receives, it is possible that vocabulary size is also affected (Huttenlocher, Haight, Bryk, Seltzer, & Lyons, 1991). This in effect could cause differences in receptive vocabulary and language production performance, which are measures used in the current study. Therefore, methods for assessing language exposure were needed.

Methods have been developed that are intended to identify the amount of exposure to each language a bilingual experiences. One such method is the language experience and proficiency questionnaire (LEAP-Q) (Marian, Blumenfeld, & Kaushanskaya, 2007). The LEAP-Q is a self-assessment tool that looks at language competence (including language proficiency, dominance and preference), age of language acquisition and the degree of language exposure for each language. As LEAP-Q was developed for assessing adult and adolescent bilingual and multilingual language experiences irrespective of the languages involved, the tool can be used with many populations and the results are generalizable across groups. The LEAP-Q is a reliable tool to assess bilingual language profiles (Marian et al., 2007).

However a disadvantage of LEAP-Q is that it is aimed at individuals who have secondary school level of literacy, therefore the questionnaire cannot be administered to children. Hence, it was necessary to modify the questions so that they were directed at the parents of children. Thereby parental reports of child language status was obtained instead of a self-assessed language profile from the children. As a number of studies have used parent and teacher reports on children's language status and have shown that they can accurately capture a child's language profiles (Chincotta & Underwood, 1998; Gutierrez-Clellen & Kreiter, 2003; Marchman et al., 2004).

Other researchers in the field have developed a web-based interface where language history questionnaires can be set up online and either administrated over the web or printed out and filled in manually (Li, Sepanski, & Zhao, 2006; Li, Zhang, Tsai, & Puls, 2014). This tool is useful as it allows researchers to select the questions that they want that are relevant to their research. The questions available in the tool are based on the most commonly-asked questions used in questionnaires based on 41 published studies in the bilingualism literature. The validity and reliability of these questions have been assessed (Li et al., 2006). This online language history questionnaire tool was therefore useful for the current research as questions relevant for assessing children's language profiles, rather than those of adults, can be selected and adapted for use in this experiment.

Several methods can be used to analyse the results from the questionnaires. Firstly, the percentage of time that a child is exposed to each language in school and at home can be assessed and compared (Unsworth et al., 2011; Whitford & Titone, 2012). Secondly, the length of exposure to each language based on their age of language acquisition and the child's current age can be calculated. For example a child aged 5 who started to learn English at age 3 would have had 2 years of English language exposure (Unsworth et al., 2011). Finally, a further measure that can be calculated is the cumulative length of exposure to each language (Gutierrez-Clellen & Kreiter, 2003; Unsworth, 2013; Unsworth et al., 2011). As the amount of language exposure varies over the life of an individual, a more representative measure would be to calculate the cumulative amount of exposure based on the amount of exposure to the language in every year of an individual's life. This is worked out by adding the percentage of exposure to the language every year to the participant's current age. For example a child aged 5 who started to learn English at age 3 may have only been exposed to the language for 25% of the time at age 3, but then have been exposed to it 50% of the time for the following two years, thus their cumulative exposure to English would be 1.25 years (0.25+0.5+0.5=1.25).

7.5.2.2.2 Language History Questionnaire adapted for this experiment

For the current study, the language history questionnaire web tool was used to create the questionnaire administered to the children and their parents (Li et al., 2006, 2014). Questions that were relevant for a child population that were concerned with language exposure were selected. An extra question, to determine cumulative language exposure, was adapted from Gutierrez-Clellen and Kreiter (2003) and added to the end of the questionnaire (Appendix H).

It was decided that the final language questionnaire would be administered to children as well as their parents in order to gain and check the information provided by the children. This should help assess whether children's responses can be used to determine language exposure instead of having to obtain the information from their parents.

Vereecken, Vandervorst, Nicklas, Covents, and Maes (2010) have shown that nursery children's test-retest reliability is good when they are given questionnaires, i.e. they are able to provide similar answers to questions that they were asked formerly. Furthermore Nicklas et al. (2010) found that parents' and children's reports had moderate agreement, which demonstrated that parents do have some sense of what children think and vice versa.

The language history questionnaire was thus administered to the children and their parents to see whether they would give consistent responses. Two copies of the language history questionnaire were given to parents, one for the parents to complete and the second for the parents to administer to their children. Questionnaires were completed in participants' own time and copies were returned by hand or via email. Parents administered the questionnaires to their children to reduce fatigue (relative to the experimenter administering it after the long experiment). Also parents were better placed to get the children to understand the questions, especially important with the Cantonese monolingual group.

7.6 Results

Data obtained from the Cantonese-English bilingual and Cantonese monolingual children were added to the data obtained in Chapter 6.

7.6.1 *Participant Descriptives*

7.6.1.1 **BPVS**

The standardised BPVS score of the participants within each language group (English monolingual, Cantonese-English bilingual, Cantonese monolingual) were checked to ensure that none of the participants differed significantly from others in their language group.

Although in theory the Cantonese monolinguals should not be able to complete this task as they were expected not to know any English, the BPVS score for all Cantonese monolinguals indicated some knowledge of English. By checking whether any of the participants' scores fell outside 1.5 times the interquartile range of scores of the other participants in their language group, it was ensured that the children's English levels were comparable within their respective language group.

The mean standardised score on the BPVS for the English monolinguals was 105.74 (range 81 to 126), for the Cantonese-English bilinguals was 89.91 (range 65 to 126) and for the Cantonese monolinguals was 76.32 (range 41 to 107). None of the participants' scores differed significantly (exceeded 1.5 times the interquartile range) from those of the other members of their language group. Consequently, all the participants were included in the analyses.

A one–way analysis of variance was conducted on the BPVS scores of the three language groups to see if they differed significantly across language groups. A significant difference was found ($F(2, 74) = 21.274$, $p < .001$). *Post hoc* tests using the Bonferroni correction indicated that there was a significant difference between the BPVS scores of the English monolinguals and the bilinguals ($p = .003$), and between the English monolinguals and the Cantonese monolinguals ($p < .001$). Furthermore, there was also a significant difference between the bilingual group and the Cantonese monolinguals ($p = .022$). This indicated that the English levels of the three language groups were significantly different from one another.

It was noted that the BPVS scores revealed that all of the Cantonese monolinguals knew some English vocabulary. This can also be seen from the language exposure descriptives in Table 7-4 (section 7.5.1.2), which indicates that Cantonese monolinguals had exposure to English at home and at school.

7.6.1.2 **Language History Questionnaire**

Parents of all the participants returned the parent's responses to the language history questionnaire, but only the monolingual group and one child from the bilingual group returned the child responses to the questionnaire. The results of the parent versions of the language history questionnaire helped to determine exposure to different languages and the possible effects this could have on repetition performance.

After receiving feedback from the parents on questions on the language history questionnaire, it was found that all parents struggled with questions relating to the estimation of time their child spent on activities (questions 9 and 10 of the questionnaire (Appendix H)). In particular they felt that responses to these questions would be unhelpful to the research especially for the version of the questionnaire administered to the children. Specifically, the parents felt that their child could not understand the concept of time because of their ages. Based on this, it was decided that the answers to these questions would not be included in the analyses.

The questionnaire also contained questions that were not applicable to the participants studied, such as those asking about immigration and the learning of languages through software packages. Therefore, any questions that resulted in 50% or more missing responses were omitted from the language history questionnaire analysis.

One of the questions analysed from the language history questionnaire was the age at which children learned English by speaking, reading and writing (

Table 7-5). Independent samples *t*-tests that compared language group (Cantonese-English bilinguals and Cantonese monolinguals) on these three factors were conducted (Table 7-6). It was found that the Cantonese-English bilinguals and the Cantonese monolingual group differed significantly in the ages at which they learned English through speaking and reading, but not writing.

Table 7-5 shows that the bilinguals learned Cantonese at younger ages than the monolinguals.

Table 7-5. *Descriptive statistics about the age at which children from the two language groups learned English by speaking, reading and writing.*

Learnt English	**Language Group**	***N***	***M***	***SD***
Through Speaking	Cantonese Monolingual	22	2.363	.966
	Cantonese-English Bilingual	22	1.205	.959
Through Reading	Cantonese Monolingual	22	3.432	1.256
	Cantonese-English Bilingual	20	1.925	1.054
Through Writing	Cantonese Monolingual	22	3.318	1.041
	Cantonese-English Bilingual	19	2.947	.621

Table 7-6. *Results from independent samples t-tests that compared the age at which children from the two language groups learn English by speaking, reading and writing. Those with an asterisk are significant.*

Learnt English	***t***	***df***	***p***
Through Speaking	3.993	42	< .001*
Through Reading	4.187	40	< .001*
Through Writing	1.406	35	.169 (equal variances not assumed)

The same analysis was made to compare the ages at which the two language groups learned Cantonese through speaking, reading and writing (Table 7-7). The independent samples *t*-tests comparing language group on these three factors were all significant (Table 7-8). Table 7-7 shows that the bilinguals learned Cantonese at a younger age than the monolinguals. The same effect was found in the earlier analysis on English.

Table 7-7. *Descriptive statistics for the age at which children from the two language groups learn Cantonese by speaking, reading and writing.*

Learnt Cantonese	**Language Group**	***N***	***M***	***SD***
Through Speaking	Cantonese Monolingual	22	1.310	.717
	Cantonese-English Bilingual	22	.705	.667
Through Reading	Cantonese Monolingual	17	3.250	1.591
	Cantonese-English Bilingual	21	1.905	1.044
Through Writing	Cantonese Monolingual	15	4.033	1.274
	Cantonese-English Bilingual	19	2.868	.814

Table 7-8. *Results from independent samples t-tests that compared the age at which children from the two language groups learned Cantonese by speaking, reading and writing. Those with an asterisk are significant.*

Learnt Cantonese	***t***	***df***	***p***
Through Speaking	2.903	42	.006*
Through Reading	3.134	36	.003*
Through Writing	3.079	23	.005 (equal variances not assumed)*

Although statistics on the ages at which children learned the languages can provide insights into the background of the language groups, they do not provide a comprehensive picture of their language exposure. Table 7-3 (section 7.5.1.1) and Table 7-4 (section 7.5.1.2) provide descriptive statistics for the percentage of the children's lives during which they were exposed (cumulative exposure) to English and Cantonese at home, and English and Cantonese at school.

Cumulative language exposure was better at helping to determine how much time each child spent learning the two languages. Independent samples *t*-tests that compared the two language groups for their cumulative English and Cantonese exposure at home and at school were conducted (Table 7-9). It was found that the two language groups only differed significantly in regards to their English and Cantonese exposure at school. The bilingual group had more English language exposure at school (Table 7-3 in section 7.5.1.1), whereas the monolingual group had more Cantonese exposure at school (Table 7-4 in section 7.5.1.2).

Table 7-9. *Results from independent samples t-test that compared Cantonese-English bilinguals' and Cantonese monolinguals' percentage of their lives spent exposed to English and Cantonese at home and at school. Those with an asterisk were significant.*

Language Exposure	***t***	***df***	***p***
English at Home	.607	42	.547
English at School	7.805	42	< .001*
Cantonese at Home	.907	42	.369
Cantonese at School	8.175	36	< .001 (equal variances not assumed)*

7.6.1.3 **Age**

A one-way between groups analysis of variance was conducted to explore the exact ages of the children for all three language groups for children under age 5 to see if there were any differences between the language groups. As Levene's, Welch's and Brown-Forsythe's tests were all significant ($p < .001$), *post hoc* tests with Games-Howell's correction were conducted. The *post hoc* analyses revealed significant differences between all language group comparisons ($p < .001$ for all three tests).

Another one-way between groups analysis of variance was conducted to explore the exact ages of the children for all three language groups for children in the groups aged 5 and over to see if there were any differences. Again, Levene's, Welch's and Brown-Forsythe's tests were all significant ($p < .001$), so *post hoc* tests with Games-Howell's correction were conducted. The *post hoc* analyses revealed that the English monolinguals were significantly different from the other two language groups ($p < .001$ for both comparisons), and the Cantonese-English monolinguals and Cantonese monolinguals' age differences also approached significance ($p = .059$)

The results from the two one-way between groups analyses of variance on participants' exact age (dependent variable) between the three language groups for the two age groups (under 5, aged 5 and over), revealed a significant difference across all language groups. This suggests that the ages of the children in both the younger and older age group varied amongst the three language groups. The effects of age were taken out in ANCOVAs below.

As shown in Experiment Two (Chapter 6), age group had a main effect on repetition accuracy, thus this is a factor that needs to be controlled for. Hence as a result of the significant difference found in exact age of the three language groups and for both age groups (under 5, aged 5 and over), in the following comparisons made on the data from the repetition task, the effect of age was partialed out in the statistical tests by entering the exact age of the participants as a covariate into the model. As the exact age of the participants was entered into the models as a covariate, individual differences in age were taken into account before other factors were looked at (language group and neighbourhood density). Although this loses the factor of age group in the analyses, which was explored in Experiment Two (Chapter 6), the statistical tests are more robust and allow definite conclusions about the factors of language group and neighbourhood density on repetition accuracy.

7.6.2 *Comparison One: Difference between words known at age 3 and non-words*

Statistical tests were conducted to investigate the effects of first- and second-order neighbourhood density and word-non-word effects (i.e. whether a phone string is treated as a word or a non-word) in the repetition accuracies of children in different language groups (English monolingual, Cantonese-English bilingual, Cantonese monolingual). The non-words included words not known until age 5.

The goal of the separate analyses of variance conducted for these two phone string sets and the results of the corresponding Levene's test are summarized in Table 7-10 (each row represents one analysis of variance conducted). The way this table is presented corresponds with the presentation in the second experiment (Chapter 6). Again, when Levene's test was significant (equal variances not assumed), a more stringent significance level was used to interpret the results taking account of the unequal variances of the groups. An adjusted significance value of *p*

$< .01$ was used (Weiner et al., 2003). These analyses and their results are discussed in the following sections.

Table 7-10. *Goal and results of Levene's test for the analysis of variance conducted.*

	Goal	**Factors in Analysis of Variance**	**Results of Levene's Test**	**Adjusted Signifi-cance**
1	Access the influence of the three language groups on the processing of the word set with different first-order neighbourhood densities	Impact of language group on the repetition accuracy for the set of words with different first-order (high, low) neighbourhood densities	$p < .001$	$p < .01$
2	Access the influence of the three language groups on the processing of the non-word set with different first-order neighbourhood densities	Impact of language group on the repetition accuracy for the set of non-words with different first-order (high, low) neighbourhood densities	$p < .001$	$p < .01$
3	To see if word/non-word status affects the processing of phone strings with the same first-order neighbourhood densities	Impact of language group on the repetition accuracy of phone strings with different first-order (high, low) neighbourhood densities	$p < .001$	$p < .01$
4	Access the influence of the three language groups on the processing of the word set with different second-order neighbourhood densities	Impact of language group on the repetition accuracy for the set of words with different second-order neighbourhood densities (HH, HL, LH, LL)	$p < .001$	$p < .01$
5	Access the influence of the three language groups on the processing of the non-word set with different second-order neighbourhood densities	Impact of language group on the repetition accuracy for the non-words with different second-order neighbourhood densities (HH, HL, LH, LL)	$p < .001$	$p < .01$
6	To see if word/non-word status affects the processing of phone strings with the same second-order neighbourhood densities	Impact of language group on the repetition accuracy on phone strings with different second-order neighbourhood densities (HH, HL, LH, LL)	$p < .001$	$p < .01$

7.6.2.1 **First-Order Neighbourhood Density**

7.6.2.1.1 Comparison of high and low first-order neighbourhood density phone strings within words and non-words

Table 7-11 shows the descriptive statistics for the repetition accuracy of children from the three language groups on words and non-words with high and low first-order neighbourhood densities. To see if the three language groups process these phone strings differently because of their language background, two 3 by 2 analyses of covariance were conducted as indicated in Rows 1 and 2 of Table 7-10.

For the word set, the interaction between language group and first-order neighbourhood density of the words approached significance and there was also a main effect of language group (Table 7-12). However, no main effect of first-order neighbourhood density was found. Conversely, a relationship between participants' age and their repetition scores was found. This suggests that children in the different language groups differed significantly in their repetition accuracy and that neighbourhood density effects only occur when participants' language group was taken into account.

Table 7-11. *Descriptive statistics for the repetition accuracy of high and low first-order neighbours in children from the three language groups for words and non-words.*

	Language Group	**First-order Neighbours**	***N***	***M***	***SD***
Word	English Monolinguals	High	372	.828	.378
		Low	372	.804	.398
	Cantonese-English Bilinguals	High	264	.617	.487
		Low	264	.712	.454
	Cantonese Monolinguals	High	264	.693	.462
		Low	264	.663	.474
Non-word	English Monolinguals	High	682	.815	.389
		Low	744	.816	.388
	Cantonese-English Bilinguals	High	484	.607	.489
		Low	528	.600	.490
	Cantonese Monolinguals	High	484	.686	.465
		Low	528	.669	.471

Table 7-12. *Results from a 3 by 2 analysis of covariance for the factors of language group and first-order neighbourhood density in words known at age 3 and non-words. Those marked with an asterisk were significant or approached significance (a p of < .01 was needed for significance).*

	Factors	***df***	***F***	***p***	**Partial eta squared**
Word	Language and First-Order Neighbourhood Density Interaction	(2, 1799)	3.661	.026*	.004
	Main Effect of First-Order Neighbourhood Density	(1, 1799)	.418	.518	< .001
	Main Effect of Language	(2, 1799)	34.829	< .001*	.037
	Main Effect of Age	(1, 1799)	30.795	< .001*	.017
Non-Word	Language and First-Order Neighbourhood Density Interaction	(2, 3449)	.124	.883	< .001
	Main Effect of First-Order Neighbourhood Density	(1, 3449)	.274	.600	< .001
	Main Effect of Language	(2, 3449)	100.334	< .001*	.055
	Main Effect of Age	(1, 3449)	68.921	< .001*	.020

Although the language group and first-order neighbourhood density interaction was not significant because of the stringent significance level that was used to evaluate the results, a *p* value of .026 would normally have been considered significant. As argued in Chapter 6, a significant effect could have been obtained if a larger sample of participants were tested, thus this result and any others that follows with a *p* < .05 would be interpreted as approaching significance.

Figure 7-2 shows that both groups of monolinguals were more accurate on words with high first-order neighbourhood density, whereas, the bilingual group were more accurate on words with low first-order neighbourhood density. This indicates that high first-order neighbourhood density has an adverse effect on the bilinguals.

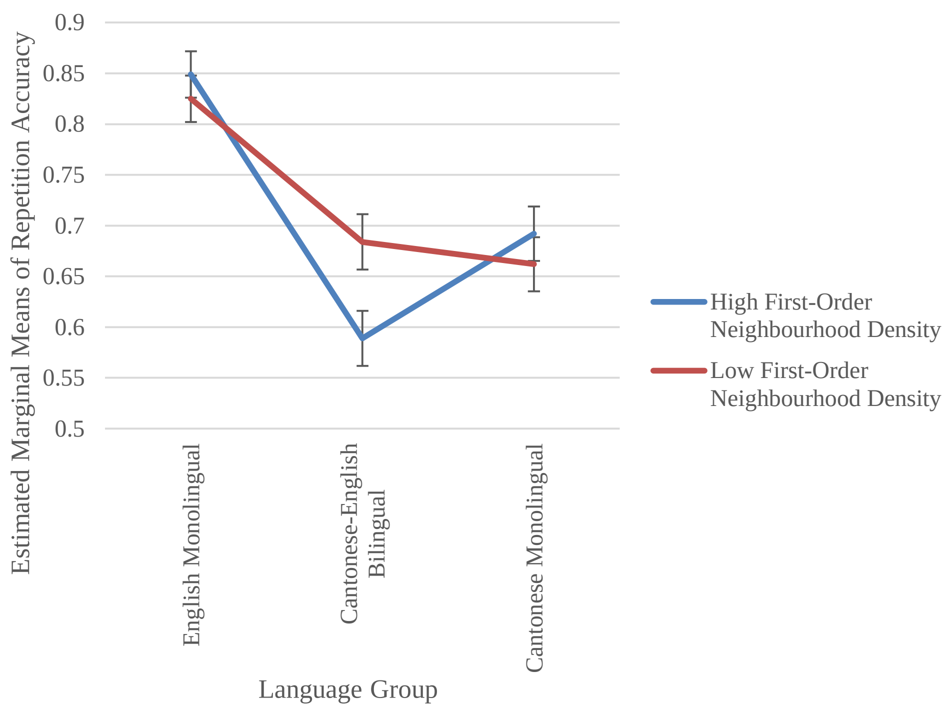

Figure 7-2. Plot illustrating the estimated marginal means of repetition accuracy for words and non-words with high first-order neighbourhood density in different language groups. Error bars indicate standard errors.

In contrast to the word set, the non-word set showed no significant interaction between language group and first-order neighbourhood density of the non-words, nor a main effect of first-order neighbourhood density (Table 7-12). However, a relationship between participants' age and their repetition scores was found and there was also a main effect of language group. The adjusted mean repetition accuracy showed that the English monolinguals (*M* = .838, *SE* = .014) performed better than the other two groups, followed by the Cantonese monolinguals (*M* = .676, *SE* = .014) who were more accurate than the Cantonese-English bilinguals (*M* = .573, *SE* = .014). For the rest of the analyses, where a main effect of language group was found, the same pattern of results was observed where the English monolinguals were the most accurate and the bilinguals were the least accurate.

7.6.2.1.2 Comparison of high and low first-order neighbourhood density phone strings between words and non-words

As with the within-word and non-word comparisons reported previously, in order to determine whether language group and the word/non-word status of a phone string with the same first-order neighbourhood densities affected processing, a 3 by 2 analysis of covariance was conducted.as described in Row 3 in Table 7-10.

For phone strings with high first-order neighbourhood density, a relationship between participants' age and repetition scores was found (Table 7-13). However, the interaction between language group and phone strings with high first-order neighbourhood density was not significant. This showed that there were no high first-order neighbourhood density word/non-word differences across language groups. There was also no main effect of first-order neighbourhood density. But, a main effect of language group was found that showed the same repetition accuracy pattern (adjusted mean repetition accuracy: English monolinguals (*M* = .843, *SE* = .014), Cantonese monolinguals (*M* = .688, *SE* = .017), Cantonese-English bilinguals (*M* = .584, *SE* = .017)). As no interaction was found, it can be inferred that there was no phone string repetition accuracy advantage for the Cantonese-English bilingual group over the Cantonese monolinguals when words and non-words with high first-order neighbourhood density were compared.

Table 7-13. *Results from a 3 by 2 analysis of covariance for the factors of language group and high and low first-order neighbourhood density between words known at age 3 and non-words. Those marked with an asterisk were significant.*

First-Order Neighbourhood Density	**Factors**	***df***	***F***	***p***	**Partial eta squared**
High	Language and First-Order Neighbourhood Density Interaction	(2, 2549)	.008	.992	< .001
	Main Effect of First-Order Neighbourhood Density	(1, 2549)	.296	.587	< .001
	Main Effect of Language	(2, 2549)	65.439	< .001*	.049
	Main Effect of Age	(1, 2549)	44.140	< .001*	.017
Low	Language and First-Order Neighbourhood Density Interaction	(2, 2699)	4.771	.009*	.004
	Main Effect of First-Order Neighbourhood Density	(1, 2699)	2.990	.084	.001
	Main Effect of Language	(2, 2699)	50.221	< .001*	.036
	Main Effect of Age	(1, 2699)	55.663	< .001*	.020

For phone strings with low first-order neighbourhood density, a relationship between participants' age and repetition scores was found (Table 7-13). The interaction between language group and phone strings with low first-order neighbourhood density was also significant, but there was no main effect of first-order neighbourhood density.

Figure 7-3 shows the interaction between the language groups and words and non-words with low first-order neighbourhood density. The graph shows that both groups of monolinguals did not vary in their word-non-word repetition accuracy for phone strings with low first-order neighbourhood densities. However, the bilinguals showed a word advantage over non-words. Although the main effect of language group indicated that the English monolinguals performed the best, followed by the Cantonese monolinguals and then finally the Cantonese-English bilinguals, the interaction showed that the Cantonese monolingual advantage over the bilinguals only occurred for the non-words. For the word set, the order of accuracy of the language groups followed that predicted by both the Extended Vocabulary and the Reduced Vocabulary Models.

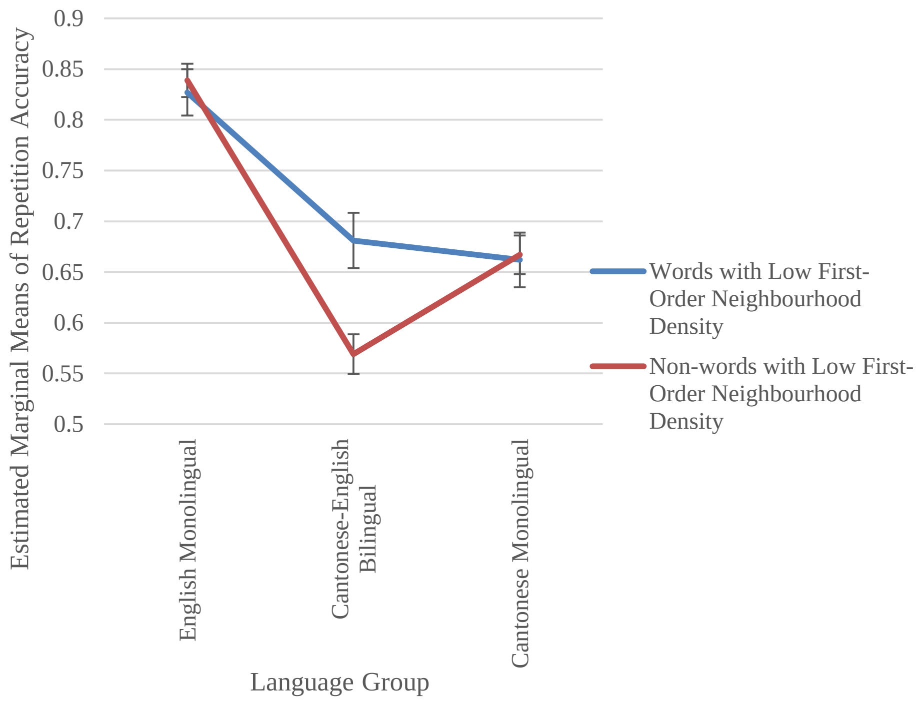

Figure 7-3. Plot illustrating the estimated marginal means of repetition accuracy with words and non-words with high first-order neighbourhood density in different language groups. Error bars indicate standard errors.

7.6.2.2 **Second-Order Neighbourhood Density**

7.6.2.2.1 Comparison of HH, HL, LH, and LL within words and non-words

Table 7-14 shows the descriptive statistics for the repetition accuracy of children from the different language groups on words and non-words in the different second-order neighbourhood density groups (HH, HL, LH, LL). As with the analysis conducted on first-order neighbourhood density, 3 by 4 analyses of covariance were conducted for: 1) words, 2) non-words. The goal of these analyses and the results of Levene's test for these are shown in Rows 4 and 5 in Table 7-10.

For the analysis of variance on words, only a relationship between participants' age and repetition scores and a main effect of language group were found (Table 7-15).

The main effect of language group followed the same patterns found previously (adjusted mean repetition accuracy: English monolinguals (*M* = .837, *SE* = .016), Cantonese monolinguals (*M* = .677, *SE* = .019), Cantonese-English bilinguals (*M* = .637, *SE* = .020)).

Table 7-14. *Descriptive statistics for the repetition accuracy of second-order neighbourhood groups (HH, HL, LH, LL) for children in the different language groups for words and non-words.*

	Age	**Second-order Neighbours**	***N***	***M***	***SD***
Word	English Monolinguals	HH	186	.796	.404
		HL	186	.860	.348
		LH	186	.806	.396
		LL	186	.801	.400
	Cantonese-English Bilinguals	HH	132	.576	.496
		HL	132	.659	.476
		LH	132	.689	.465
		LL	132	.735	.443
	Cantonese Monolinguals	HH	132	.712	.455
		HL	132	.674	.470
		LH	132	.629	.485
		LL	132	.697	.461
Non-word	English Monolinguals	HH	341	.827	.379
		HL	341	.804	.398
		LH	372	.777	.417
		LL	372	.855	.353
	Cantonese-English Bilinguals	HH	242	.612	.488
		HL	242	.603	.490
		LH	264	.534	.500
		LL	264	.667	.472
	Cantonese Monolinguals	HH	242	.690	.463
		HL	242	.682	.467
		LH	264	.682	.467
		LL	264	.655	.476

Table 7-15. *Results from a 3 by 4 analysis of covariance for the factors of language group and second-order neighbourhood density in words known at age 3 and non-words. Those marked with an asterisk were significant or approached significance (a p of < .01 was needed for significance).*

	Factors	***df***	***F***	***p***	**Partial eta squared**
Word	Language and Second-Order Neighbourhood Density Interaction	(6, 1799)	1.937	.072	.006
	Main Effect of Second-Order Neighbourhood Density	(3, 1799)	1.167	.321	.002
	Main Effect of Language	(2, 1799)	34.855	< .001*	.038
	Main Effect of Age	(1, 1799)	30.819	< .001*	.017
Non-Word	Language and Second-Order Neighbourhood Density Interaction	(6, 3449)	1.568	.152	.003
	Main Effect of Second-Order Neighbourhood Density	(3, 3449)	3.075	.027*	.003
	Main Effect of Language	(2, 3449)	100.713	< .001*	.055
	Main Effect of Age	(1, 3449)	69.181	< .001*	.020

Similarly, for the non-word set a relationship between participants' age and repetition scores was also found but there was no significant interaction between language group and second-order neighbourhood density of the non-words (Table 7-15). However, the main effect of second-order neighbourhood density approached significance. The adjusted mean repetition accuracy showed that the LL non-words were the most accurate (M = .723, SE = .015), followed by HH non-words (M = .706, SE = .015), then HL non-words (M = .693, SE = .015), and finally LH non-words (M = .661, SE = .015). There was also a main effect of language group with the same patterns found as before (adjusted mean repetition accuracy: English monolinguals (M = .838, SE = .012), Cantonese monolinguals (M = .676, SE = .014), Cantonese-English bilinguals (M = .573, SE = .014)).

7.6.2.2.2 Comparison of HH, HL, LH, and LL between words and non-words

To see if language groups and the word/non-word status of a phone string with the same second-order neighbourhood densities (HH, HL, LH and LL) affected processing, four 3 by 2 analyses of covariance were conducted as described in Row 6 in Table 7-10. HH words were compared with HH non-words, HL words were compared with HL non-words, LH words were compared with LH non-words, and LL words were compared with LL non-words.

For all the second-order neighbourhood density groups, a relationship between participants' age and repetition scores was found (Table 7-16). A main effect of language was also found for all second-order neighbourhood density sets. The direction of this effect is the same as that found in all the previous analyses.

Table 7-16. *Results from four 3 by 2 analysis of covariance for the language groups and different second-order neighbourhood density groups (HH, HL, LH and LL) between words known at age 3 and non-words. Those marked with an asterisk were significant.*

Second-Order Neighbour-hood Density	**Factors**	***df***	***F***	***p***	**Partial eta squared**
HH	Language and Second-Order Neighbourhood Density Interaction	(1, 1274)	.479	.619	.001
	Main Effect of Second-Order Neighbourhood Density	(1, 1274)	.332	.565	< .001
	Main Effect of Language	(1, 1274)	31.444	< .001*	.047
	Main Effect of Age	(1, 1274)	15.376	< .001*	.012
HL	Language and Second-Order Neighbourhood Density Interaction	(1, 1274)	.652	.521	.001
	Main Effect of Second-Order Neighbourhood Density	(1, 1274)	1.836	.176	.001
	Main Effect of Language	(1, 1274)	34.849	< .001*	.052
	Main Effect of Age	(1, 1274)	30.053	< .001*	.023
LH	Language and Second-Order Neighbourhood Density Interaction	(1, 1349)	4.821	.008*	.007
	Main Effect of Second-Order Neighbourhood Density	(1, 1349)	2.801	.094	.002
	Main Effect of Language	(1, 1349)	27.024	< .001*	.039
	Main Effect of Age	(1, 1349)	24.057	< .001*	.018
LL	Language and Second-Order Neighbourhood Density Interaction	(1, 1349)	2.472	.085	.004
	Main Effect of Second-Order Neighbourhood Density	(1, 1349)	.567	.451	< .001
	Main Effect of Language	(1, 1349)	24.317	< .001*	.035
	Main Effect of Age	(1, 1349)	32.495	< .001*	.024

The only language and second-order neighbourhood density interaction found was for the LH set. This suggests that children in the different language groups differed significantly in their repetition accuracy across LH words and non-words. Figure 7-4 shows that the bilinguals have more variable responses between words and non-words compared to the other two language groups. As with the interaction between language groups and words and non-words with low first-order neighbourhood density, there was again a word advantage over non-words for the bilingual group. Also it can be seen once again that the disadvantage in repetition accuracy in the bilingual group compared to the other two language groups is only present for the LH non-words and not the LH words.

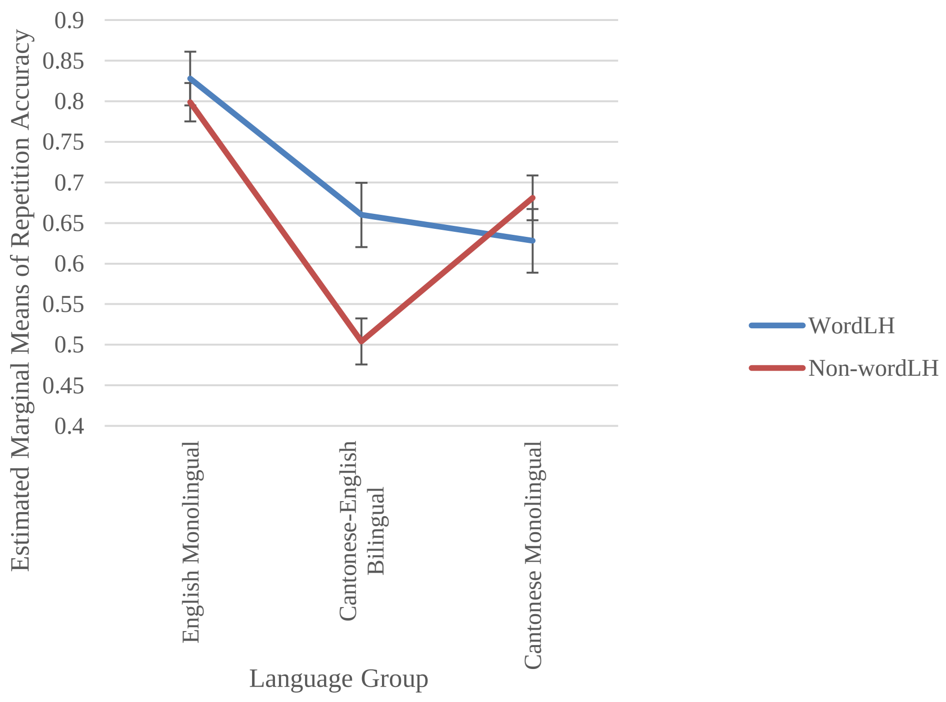

Figure 7-4. Plot illustrating the estimated marginal means of repetition accuracy with words and non-words with low first-order and high second-order neighbourhood density across language groups. Error bars indicate standard errors.

7.6.3 *Comparison Two: Difference between words not known until age 5 and pseudo-words*

Statistical tests were conducted to investigate the effects of first- and second-order neighbourhood density and word-non-word effects (whether a phone string was treated as a word or a non-word) in the repetition accuracies of children in different language groups. This time a comparison was made between words not known until age 5 and the set of pseudo-words.

The goal of the analysis of variances conducted and the results of their Levene's test are shown in Table 7-17. This table is presented in the same format as Table 7-10 for Comparison One, where each row represents one test. Levene's test was used to check the homogeneity of variance between the language groups. When Levene's test was violated, an adjusted significance value of $p < .01$ was needed for a result to be marked as significant (Weiner et al., 2003). This addressed the differences in variances between groups. These analyses and their results are discussed in the following sections.

Table 7-17. *Goal and results of Levene's test for the analysis of variance conducted.*

	Goal	**Factors in Analysis of Variance**	**Results of Levene's Test**	**Adjusted Significance**
1	Access the influence of the three language groups on the processing of the words set with different first-order neighbourhood densities	Impact of language group on the repetition accuracy for the set of words with different first-order (high, low) neighbourhood densities	$p < .001$	$p < .01$
2	Access the influence of the three language groups on the processing of the pseudo-words with different first-order neighbourhood densities	Impact of language group on the repetition accuracy for the pseudo-words with different first-order (high, low) neighbourhood densities	$p < .001$	$p < .01$
3	To see if word/non-word status affects the processing of phone strings with the same first-order neighbourhood densities	Impact of language group on the repetition accuracy of phone strings with different first-order (high, low) neighbourhood densities	$p < .001$	$p < .01$
4	Access the influence of the three language groups on the processing of the word set with different second-order neighbourhood densities	Impact of language group on the repetition accuracy for the set of words with different second-order neighbourhood densities (HH, HL, LH, LL)	$p < .001$	$p < .01$
5	Access the influence of the three language groups on the processing of the pseudo-words with different second-order neighbourhood densities	Impact of language group on the repetition accuracy for the pseudo-words with different second-order neighbourhood densities (HH, HL, LH, LL)	$p < .001$	$p < .01$
6	To see if word/non-word status affects the processing of phone strings with the same second-order neighbourhood densities	Impact of language group on the repetition accuracy on phone strings with different second-order neighbourhood densities (HH, HL, LH, LL)	$p < .001$	$p < .01$

7.6.3.1 First-Order Neighbourhood Density

7.6.3.1.1 Comparison of high and low first-order neighbourhood density phone strings within words and pseudo-words

Table 7-18 shows the descriptive statistics for the repetition accuracy of children from the three language groups on words and pseudo-words with high and low first-order neighbourhood densities. To see if the three language groups process these phone strings differently because of their language background, two 3 by 2 analysis of covariance were conducted as indicated in Rows 1 and 2 in Table 7-17.

For both words and pseudo-words a relationship between participants' ages and their repetition scores was found (Table 7-19). Neither the word set nor the pseudo-word set showed an interaction between language group and first-order neighbourhood density. However, for the word set the main effect of first-order neighbourhood density approached significance. The adjusted mean repetition accuracy showed that the high first-order neighbourhood density words (*M* = .735, *SE* = .015) were more accurate than the low first-order neighbourhood density words (*M* = .692, *SE* = .015).

As no interactions were found for the word and pseudo-word sets, analyses on the main effect of language group can be investigated directly. There was a main effect of language group for both words and pseudo-words with the same patterns found in Comparison One. The adjusted mean repetition accuracies were: English monolinguals (*M* = .859, *SE* = .016), Cantonese monolinguals (*M* = .675, *SE* = .019), Cantonese-English bilinguals (*M* = .607, *SE* = .019) for the word set. The adjusted mean repetition accuracy were: English monolinguals (*M* = .816, *SE* = .018), Cantonese monolinguals (*M* = .675, *SE* = .020), Cantonese-English bilinguals (*M* = .532, *SE* = .021) for the pseudo-word set.

Table 7-18. *Descriptive statistics for the repetition accuracy of high and low first-order neighbours in children from the three language groups for words and pseudo-words.*

	Language Group	**First-order Neighbours**	***N***	***M***	***SD***
Word	English Monolinguals	High	372	.836	.371
		Low	372	.839	.368
	Cantonese-English Bilinguals	High	264	.670	.471
		Low	264	.602	.490
	Cantonese Monolinguals	High	264	.708	.455
		Low	264	.644	.480
Pseudo-word	English Monolinguals	High	310	.790	.408
		Low	372	.793	.406
	Cantonese-English Bilinguals	High	220	.532	.500
		Low	264	.598	.491
	Cantonese Monolinguals	High	220	.659	.475
		Low	264	.693	.462

Table 7-19. *Results from a 3 by 2 analysis of covariance for the factors of language group and first-order neighbourhood density in words known at age 3 and pseudo-words. Those marked with an asterisk were significant or approached significance (a p of < .01 was needed for significance).*

	Factors	***df***	***F***	***p***	**Partial eta squared**
Word	Language and First-Order Neighbourhood Density Interaction	(2, 1799)	1.406	.246	.002
	Main Effect of First-Order Neighbourhood Density	(1, 1799)	4.442	.035*	.002
	Main Effect of Language	(2, 1799)	53.100	< .001*	.056
	Main Effect of Age	(1, 1799)	33.599	< .001*	.018
Pseudo-Word	Language and First-Order Neighbourhood Density Interaction	(2, 1649)	.722	.486	.001
	Main Effect of First-Order Neighbourhood Density	(1, 1649)	2.366	.124	.001
	Main Effect of Language	(2, 1649)	50.320	< .001*	.058
	Main Effect of Age	(1, 1649)	69.181	< .001*	.020

7.6.3.1.2 Comparison of high and low first-order neighbourhood density phone strings between words and pseudo-words

To see if language group and word/non-word status affects the processing of phone strings with the same first-order neighbourhood densities a 3 by 2 analysis of variance was conducted as described in Row 3 in Table 7-17,

For both the phone strings with high and low first-order neighbourhood density, a relationship between participants' ages and their repetition scores was found (Table 7-20). The interaction between language group and phone strings with high first-order neighbourhood density was not significant. However, there was a main effect of first-order neighbourhood density, where the adjusted mean repetition accuracy showed that the high first-order neighbourhood density words (*M* = .736, *SE* = .015) were more accurate than the pseudo-words (*M* = .658, *SE* = .016). A main effect of language group with was also found. Once again the same patterns emerged (adjusted mean repetition accuracy: English monolinguals (*M* = .833, *SE* = .017), Cantonese monolinguals (*M* = .683, *SE* = .020), Cantonese-English bilinguals (*M* = .574, *SE* = .021)).

Table 7-20. *Results from a 3 by 2 analysis of covariance for the factors of language group and high and low first-order neighbourhood density between words not known until age 5 and pseudo-words. Those marked with an asterisk were significant.*

First-Order Neighbourhood Density	**Factors**	***df***	***F***	***p***	**Partial eta squared**
High	Language and First-Order Neighbourhood Density Interaction	(2, 1649)	1.856	.157	.002
	Main Effect of First-Order Neighbourhood Density	(1, 1649)	12.625	< .001*	.008
	Main Effect of Language	(2, 1649)	45.434	< .001*	.052
	Main Effect of Age	(1, 1649)	26.177	< .001*	.016
Low	Language and First-Order Neighbourhood Density Interaction	(2, 1799)	1.803	.165	.002
	Main Effect of First-Order Neighbourhood Density	(1, 1799)	< .001	.997	< .001
	Main Effect of Language	(2, 1799)	56.790	< .001*	.060
	Main Effect of Age	(1, 1799)	43.739	< .001*	.024

For phone strings with low first-order neighbourhood density, no interaction occurred (Table 7-20). There was also no main effect of first-order neighbourhood density, but a main effect of language group was found once again. The same pattern follows those observed before (adjusted mean repetition accuracy: English monolinguals (*M* = .841, *SE* = .017), Cantonese monolinguals (*M* = .667, *SE* = .019) Cantonese-English bilinguals (*M* = .566, *SE* = .020). As no interaction was found for both high and low first-order neighbourhood density, the main effects of language group illustrates a clear bilingual and Cantonese monolingual phone string repetition disadvantage compared to the English monolinguals.

7.6.3.2 **Second-Order Neighbourhood Density**

7.6.3.2.1 Comparison of HH, HL, LH, and LL within words and pseudo-words

Table 7-21 shows the descriptive statistics for the repetition accuracy of children from the three language groups on words not known until age 5 and pseudo-words with different second-order neighbourhood densities (HH, HL, LH and LL). Two 3 by 4 analyses of covariance were conducted as described in Rows 4 and 5 in Table 7-17.

A relationship between participants' ages and their repetition scores was found for both words and pseudo-words (Table 7-22). For the word set, the interaction effect between language group and second-order neighbourhood density of the words was significant. There was also a main effect of language group and a main effect of second-order neighbourhood density. This suggests that children in the different language groups differed significantly in their repetition accuracy.

Table 7-21. *Descriptive statistics for the repetition accuracy of second-order neighbourhood groups (HH, HL, LH, LL) for children in the different language groups for words and pseudo-words.*

	Age	**Second-order Neighbours**	***N***	***M***	***SD***
Word	English Monolinguals	HH	186	.839	.369
		HL	186	.833	.374
		LH	186	.780	.416
		LL	186	.898	.304
	Cantonese-English Bilinguals	HH	132	.636	.483
		HL	132	.705	.458
		LH	132	.402	.492
		LL	132	.803	.399
	Cantonese Monolinguals	HH	132	.697	.461
		HL	132	.720	.451
		LH	132	.568	.497
		LL	132	.720	.451
Pseudo-word	English Monolinguals	HH	155	.813	.391
		HL	155	.768	.424
		LH	186	.774	.419
		LL	186	.812	.392
	Cantonese-English Bilinguals	HH	110	.582	.496
		HL	110	.482	.502
		LH	132	.667	.473
		LL	132	.530	.501
	Cantonese Monolinguals	HH	110	.682	.468
		HL	110	.636	.483
		LH	132	.795	.405
		LL	132	.591	.493

Table 7-22. *Results from a 3 by 2 analysis of covariance for the factors of language group and first-order neighbourhood density in words known at age 3 and pseudo-words. Those marked with an asterisk were significant or approached significance (a p of < .01 was needed for significance).*

	Factors	***df***	***F***	***p***	**Partial eta squared**
Word	Language and Second-Order Neighbourhood Density Interaction	(6, 1799)	3.895	.001*	.013
	Main Effect of Second-Order Neighbourhood Density	(3, 1799)	22.438	< .001*	.036
	Main Effect of Language	(2, 1799)	55.220	< .001*	.058
	Main Effect of Age	(1, 1799)	34.940	< .001*	.019
Pseudo-Word	Language and Second-Order Neighbourhood Density Interaction	(6, 1649)	2.459	.023*	.009
	Main Effect of Second-Order Neighbourhood Density	(3, 1649)	5.810	.001*	.011
	Main Effect of Language	(2, 1649)	50.901	.001*	.059
	Main Effect of Age	(1, 1649)	69.181	< .001*	.020

Figure 7-5 below shows the interaction between language group and second-order neighbourhood density of words. From the plot it can be seen that the bilinguals were disproportionately affected by neighbourhood density for LH words compared to the other two groups. The LH phone string set appears to be the least accurate set for all language groups but most noticeably so for both the Cantonese-English bilinguals and the Cantonese monolinguals.

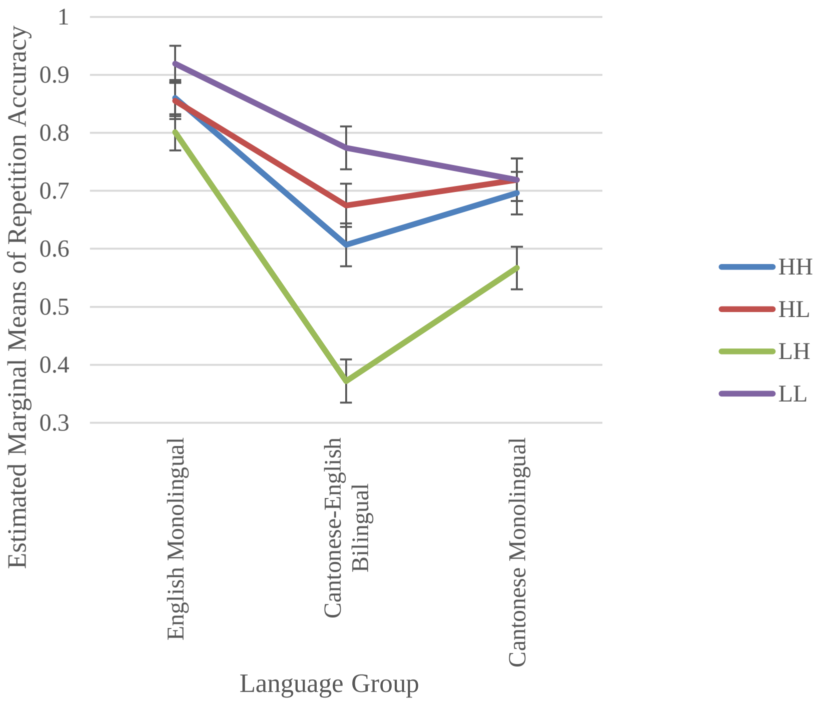

Figure 7-5. Plot illustrating the estimated marginal means of repetition accuracy with words with different neighbourhood densities across languages groups. Error bars indicate standard errors.

For the pseudo-word set, the interaction between language group and second-order neighbourhood density approached significance. There was also a main effect of language group, and a main effect of second-order neighbourhood density. This suggests that children in the different language groups differed significantly in their pseudo-word repetition accuracy.

Figure 7-6 below shows that the English monolinguals were more consistent in their repetition accuracy across word sets than the other two groups. It also appears the Cantonese-English bilinguals and the Cantonese monolinguals were more accurate in the LH phone string set. This is the opposite of what was found for the word set, as the LH phone string set in that case was found to be the least accurate. Another point to note is that the Cantonese monolingual group here showed a reverse order of performance of the phone string sets to what was found in the word set. In the word set, the Cantonese monolinguals were the most accurate in the LL and HL set, followed by the HH, and finally the LH set. However, for the pseudo-words, the reverse order was found so that the LH set was the most accurate follow by HH, HL and LL sets.

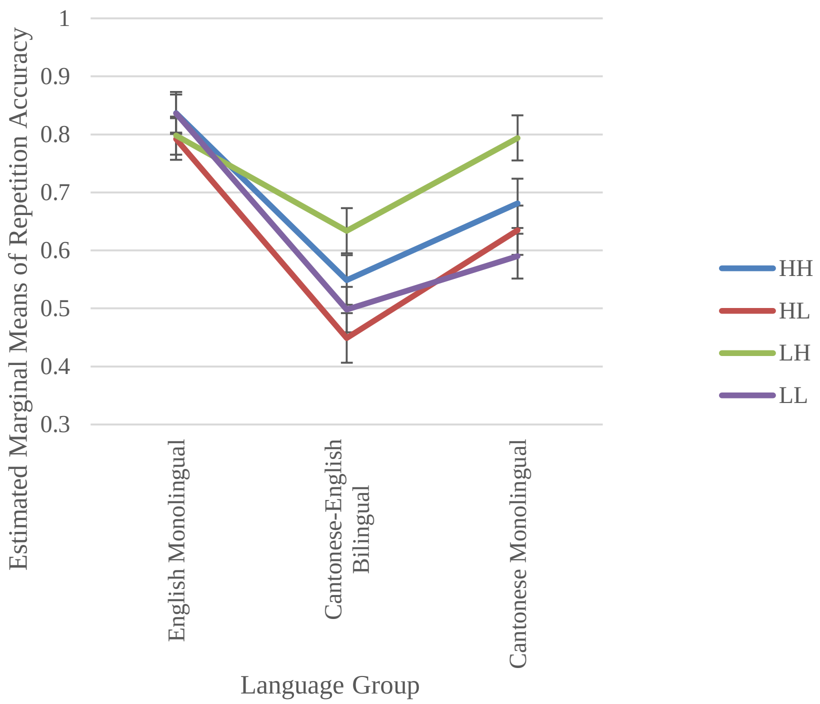

Figure 7-6. Plot illustrating the estimated marginal means of repetition accuracy with pseudo-words with different neighbourhood densities across languages groups. Error bars indicate standard errors.

7.6.3.2.2 Comparison of HH, HL, LH, and LL between words and pseudo-words

To see if children's language group and the word/non-word status of phone strings affected the repetition accuracy of phone strings with the same neighbourhood densities, four 3 by 2 analyses of variance were conducted. The goal and the results of Levene's test for these are in Row 6 of Table 7-17. As in Comparison One, HH, HL, LH and LL words were compared with their pseudo-word counterparts.

For all the second-order neighbourhood density groups, a relationship between participants' ages and their repetition scores was found (for the HH set this approached significance) (Table 7-23). A main effect of language was also found for all second-order neighbourhood density sets where the same pattern of repetition accuracy between the language groups was demonstrated.

Table 7-23. *Results from four 3 by 2 analysis of covariance for the language and second-order neighbourhood density groups (HH, HL, LH and LL) between words not known until age 5 and pseudo-words. Those marked with an asterisk were significant/approached significance (p of < .01 was needed for significance).*

Second-Order Neighbour-hood Density	**Factors**	***df***	***F***	***p***	**Partial eta squared**
HH	Language and Second-Order Neighbourhood Density Interaction	(1, 824)	.132	.876	< .001
	Main Effect of Second-Order Neighbourhood Density	(1, 824)	1.055	.305	.001
	Main Effect of Language	(1, 824)	21.062	< .001*	.049
	Main Effect of Age	(1, 824)	5.879	< .016*	.007
HL	Language and Second-Order Neighbourhood Density Interaction	(1, 824)	2.521	.081	.006
	Main Effect of Second-Order Neighbourhood Density	(1, 824)	16.030	< .001*	.019
	Main Effect of Language	(1, 824)	24.529	< .001*	.057
	Main Effect of Age	(1, 824)	23.209	< .001*	.028
LH	Language and Second-Order Neighbourhood Density Interaction	(1, 899)	8.939	< .001*	.020
	Main Effect of Second-Order Neighbourhood Density	(1, 899)	29.507	< .001*	.032
	Main Effect of Language	(1, 899)	32.329	< .001*	.068
	Main Effect of Age	(1, 899)	23.145	< .001*	.025
LL	Language and Second-Order Neighbourhood Density Interaction	(1, 899)	4.069	.017*	.009
	Main Effect of Second-Order Neighbourhood Density	(1, 899)	33.606	< .001*	.036
	Main Effect of Language	(1, 899)	31.989	< .001*	.067
	Main Effect of Age	(1, 899)	22.790	< .001*	.025

For the HL set, a main effect of second-order neighbourhood density was found where the adjusted mean repetition accuracy showed that the HL words (*M* = .749, *SE* = .021) were more accurate than the HL pseudo-words (*M* = .625, *SE* = .023). For both the LH and LL sets, a language and second-order neighbourhood density interaction was found. Figure 7-7 shows this interaction for the LH set. It can be seen that the English monolingual group performed similarly on both words and pseudo-words, but for the other two language groups pseudo-word repetition was more accurate.

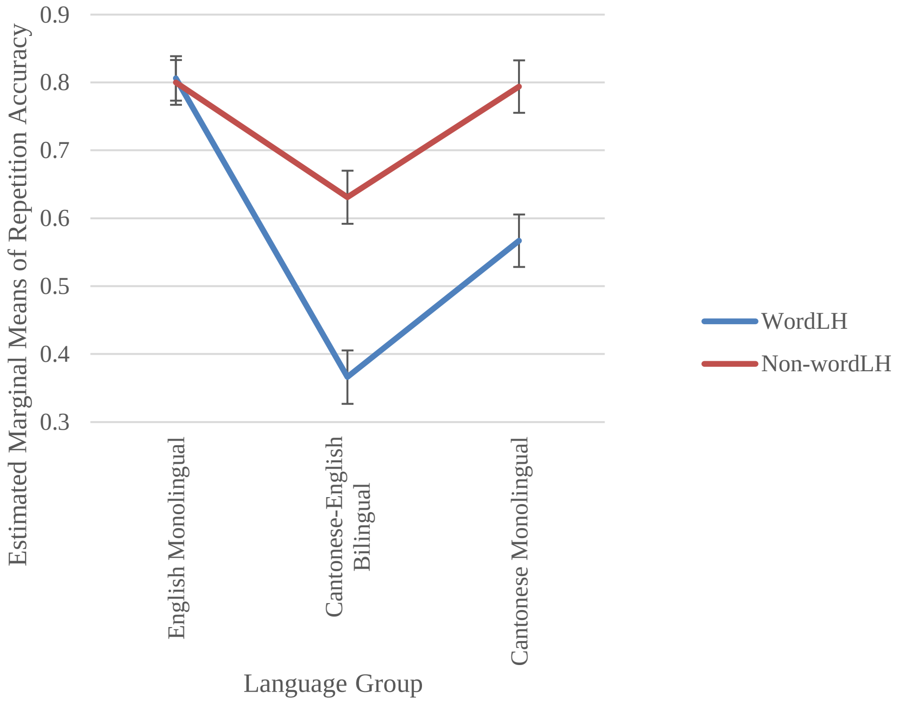

Figure 7-7. Plot illustrating the estimated marginal means of repetition accuracy with words and pseudo-words (non-words) with low first-order and high second-order neighbourhood density across language groups. Error bars indicate standard errors.

Figure 7-8 shows this interaction for the LL set. All three language groups were more accurate on the words, but the Cantonese-English bilingual group showed the greatest difference in repetition accuracies between words and pseudo-words. The performance advantage here for words over pseudo-words was the opposite of the effect found for the LH set, where pseudo-words were more accurate.

Inspection of the interactions seen with these two sets of stimuli suggests that a word/non-word difference is present across all language groups. This is particularly interesting for the Cantonese monolingual group as they were predicted to treat all the stimuli as non-words so there should not be a word/non-word repetition difference for them. Another point worth noting with respect to this interaction is that the bilingual group once again only showed a repetition accuracy disadvantage on the pseudo-words and not on the word set. For the LL words, the order of repetition accuracy of the language groups followed the predictions of the Extended Vocabulary and Reduced Vocabulary Model. This suggests that word processing can be accounted for by the Extended Vocabulary and Reduced Vocabulary Models whereas pseudo-word processing requires a different explanation.

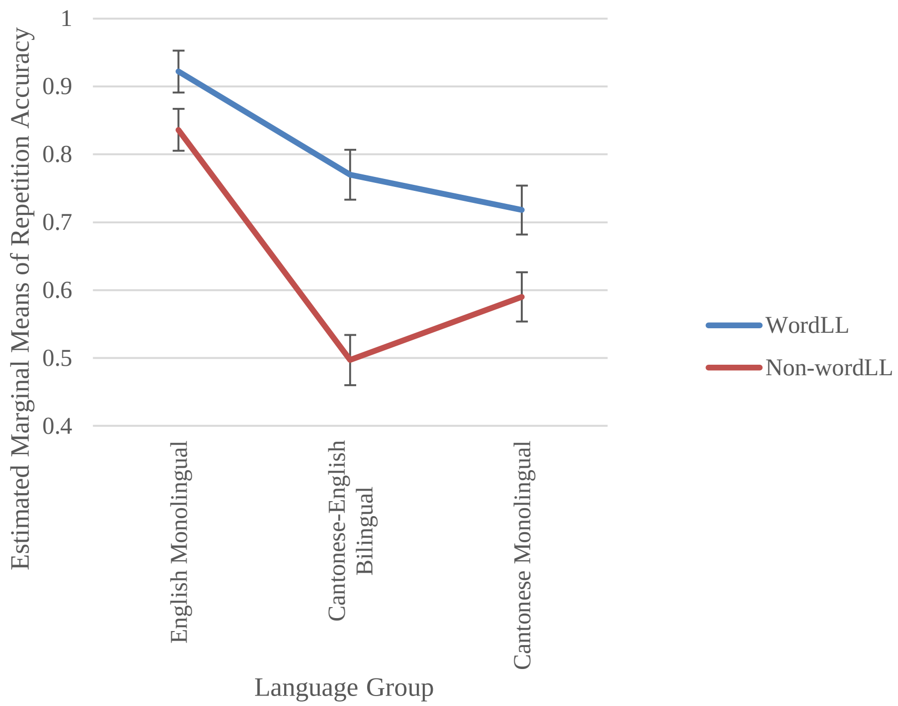

Figure 7-8. Plot illustrating the estimated marginal means of repetition accuracy with words and pseudo-words (non-words) with low first-order and second-order neighbourhood density across language groups. Error bars indicate standard errors.

7.6.4 *Language History Questionnaire Correlations with Repetition Accuracy*

To determine whether English exposure is related to phone string repetition accuracy Pearson's correlations were performed on cumulative English exposure at home and at school for the Cantonese-English bilinguals and the Cantonese monolinguals against the repetition accuracy of the different phone strings (3HH, 3HL, 3LH, 3LL, 5HH, 5HL, 5LH, 5LL, NonHH, NonHL, NonLH, NonLL (see Table 5-1 in Chapter 5 for their definitions)). Cumulative English exposure at home and at school were obtained from the parent responses to the language history questionnaire. Table 7-24 and Table 7-25 shows the results for Pearson's correlations.

Table 7-24. *Results of Pearson's Correlation on phone string repetition accuracy and cumulative English exposure at home for the Cantonese-English bilingual and Cantonese monolingual children. Those marked with an asterisk are significant.*

Phone String Type	**Pearson's Correlation**	***p***
3HH	0.108	0.081
3HL	0.148	0.016*
3LH	0.122	0.047*
3LL	0.222	< .001*
5HH	0.010	0.867
5HL	0.182	0.003*
5LH	0.054	0.387
5LL	0.248	< .001*
NonHH	0.181	0.007*
NonHL	0.133	0.049*
NonLH	0.175	0.004*
NonLL	0.108	0.080

Table 7-25. *Results of Pearson's Correlation on phone string repetition accuracy and cumulative English exposure at school for the Cantonese-English bilingual and Cantonese monolingual children. Those marked with an asterisk are significant.*

Phone String Type	**Pearson's Correlation**	***p***
3HH	-0.028	0.655
3HL	0.097	0.115
3LH	0.059	0.340
3LL	0.143	0.020*
5HH	-0.028	0.654
5HL	0.066	0.285
5LH	-0.042	0.501
5LL	0.187	0.002*
NonHH	0.013	0.853
NonHL	-0.021	0.760
NonLH	0.029	0.635
NonLL	0.064	0.301

For the correlations between English exposure at home and phone string repetition accuracy, it was found that the repetition accuracy of all phone string types correlated with English exposure at home, apart from the 3HH, 5HH, 5LH and NonLL phone strings. This shows that repetition accuracy of most of the phone strings in the stimuli can be predicted by the cumulative English exposure at home of the Cantonese-English bilinguals and Cantonese monolinguals.

On the contrary, for correlations between English exposure at school and phone string repetition accuracy, there were almost no significant correlations at all (the 3LL and 5LL phone strings were the exception). This shows that unlike English exposure at home, English exposure at school is only useful in predicting the repetition accuracies of words with low first- and second-order neighbourhood densities (LL type).

7.6.5 *Parent and Child Language History Questionnaire Reliability Analysis*

As well as using the language history questionnaire to assess children's exposure to English and Cantonese, another aim of the experiment was to see whether an improved methodology of testing can be used in obtaining language history information. The language history questionnaire was administered to both the children and their parents to see whether child responses to the questionnaire agreed with those made by the parents.

The agreement between parents and children on items on the questionnaire were analysed using a two-way random effects absolute single measure intraclass correlation coefficient (ICC) so that inter-rater reliability could be determined. The ICC was used instead of a Pearson Correlation because the ICC takes into account the variability of the individuals who filled in the questionnaire. In total, 45 parents returned the parent copy of the questionnaire, but only 20 children's copies were returned (with only one being from a bilingual child). Reasons that the questionnaires were not returned included parents forgetting to administer the child copy of the questionnaire or refusing to administer it as they believed that their child could either: 1) not understand the questionnaire, or 2) would give the same responses as their parents. As both parent and child copies of the questionnaire were returned for only one of the bilingual participants, it was not possible to compare the child and parent agreement in the language history questionnaire for the bilingual group. However, the questionnaire data from the Cantonese monolingual children and their parents were still useful in seeing whether parent and child responses to the questionnaire are similar for this language group.

After dropping the bilingual data, for the group where the 19 monolingual parents and children who filled in the language questionnaire, the children had a mean age of 6 years and 2 months (range 2 years 9 months to 11 years old). The ICC values are given in the table in Appendix I. ICC values are classified as ‘excellent’ (≥ .81), 'good' (.61 - .80), 'moderate' (.41 - .60) and 'poor' (≤ .40) (Landis & Koch, 1977). An ICC score could not be calculated for five of the 39 questions because there were too many missing answers from the parents, as some questions were considered by the parents to not be relevant to their child; this included questions about language change after immigration, the use of software to learn languages and emailing friends using Cantonese. As the question about immigration was only relevant to the bilingual language group, it was not possible to calculate an ICC for this item.

None of the questions was classified as having an excellent ICC value. Answers to four questions were designated as good, two as moderate and the rest (28 items) as poor. Overall, six items on the questionnaire had good or moderate ICC values. They constituted 15.38% of the items on the questionnaire, indicating that parent and child responses to the overall language questionnaire were not reliable overall.

7.7 Discussion

7.7.1 *Recap of the Predictions*

Research in the literature has suggested that there are neighbourhood density effects in word production between monolinguals and bilinguals. The aim of this chapter was to see if it was possible to determine whether the Extended Vocabulary Model or the Reduced Vocabulary Model was more appropriate for understanding child language development in bilinguals and monolinguals in the three language groups; English monolinguals, Cantonese-English bilinguals and Cantonese monolinguals.

The Extended Vocabulary Model predicted that all three language groups should differ from each other in their spoken repetition performances on phone strings with high and low first- and second-order neighbourhood densities, as they all have different lexicons that affect the neighbourhood density properties of the stimuli. Therefore, a phone string designated as HH neighbourhood density may not actually be a HH phone string, depending on the individual's lexicon.

On the other hand, the Reduced Vocabulary Model predicted that word repetition should be affected by how much time a child spends learning each language. Hence, this model predicted that for the word phone strings, the English monolinguals would perform the best, followed by the Cantonese-English bilinguals and then the Cantonese monolinguals, based on their time spent learning English (or in the case of the Cantonese monolinguals, they may arguably spend no time learning English).

Those who spend less time learning English would have a smaller English lexicon, so they would see words presented as stimuli as non-words compared to English monolinguals, therefore accuracy for the phone strings should decrease. The first- and second-order neighbourhood density accuracy trends for the English monolinguals and Cantonese-English bilinguals were hypothesised to be the same, as both groups have an English lexicon. The only difference should be that the Cantonese-English bilinguals should act like phonologically delayed English monolinguals as they spend less time learning English. Cantonese monolinguals on the other hand were predicted to perform significantly differently from the other two groups in terms of first- and second-order neighbourhood density, as they would arguably not have acquired any English words and would be treating all the stimuli as non-words.

Both the Extended and Reduced Vocabulary Models use the Generative Acquisition Hypothesis Processing Shift Model as a basis. The Generative Acquisition Hypothesis Processing Shift Model predicts that stimuli that are known words in the lexicon will be processed lexically, whereas stimuli not yet acquired, or that will never be acquired, such as in the case of pseudo-words, will be processed sublexically. It was argued that the Cantonese monolingual group in the study should process all phone strings sublexically as they would not have acquired any English words into their lexicon and would see all the stimuli as non-words.

It is important to note that for the predictions made, it was assumed that the Cantonese monolingual group had learned no English, so they would not have any English words in their lexicon. However, this turned out not to be the case as the Cantonese monolinguals had acquired some English words, as shown in the BPVS scores and responses from the language history questionnaire for this group. This means that it is possible the Cantonese monolinguals had acquired English through a source such as having been taught English at school or learned it through the media.

In order to check whether English and Cantonese language exposure had an influence on the repetition accuracies of the children, the language history questionnaire was administered to children and their parents. As the responses from the questionnaire determine language exposure, which is an important consideration for both the Extended and Reduced Vocabulary Model, the results from this are discussed first before going into the analysis on the repetition task.

7.7.2 *Summary of Findings*

7.7.2.1 **Results from the Language History Questionnaire**

Cantonese-English bilinguals' and Cantonese monolinguals' English and Cantonese exposure were analysed from the parent responses to the language history questionnaire. It was found that the bilinguals learned both English and Cantonese through speaking and reading at a younger age than the Cantonese monolinguals. Furthermore, when cumulative language exposure to English and Cantonese at home and at school were considered, the bilingual group had more English exposure at school than the monolinguals. Conversely, the monolingual group had more Cantonese exposure at school than the bilinguals. Yet cumulative English and Cantonese exposure at home were not significantly different for the two groups.

The results from the language history questionnaire therefore show that the fundamental difference between the Cantonese-English bilingual and Cantonese monolingual groups in language exposure lies in their English and Cantonese exposure at school. Thus it can be argued that the two language groups may not be that different, especially for the children in the younger age group who would have only spent a short amount of time in school.

It can also be seen from the results of the language history questionnaire that the Cantonese monolingual group has learnt English, being exposed to it both at home and in school. Therefore, the Cantonese monolingual group are not true Cantonese monolinguals because they have knowledge of English and they have English vocabulary in their lexicon. However, for the purpose of this study, we will continue to name this group the Cantonese monolingual group when the rest of the findings are discussed.

7.7.2.2 **Results from the Repetition Task**

Based on the findings from Experiment Two (Chapter 6), clear age differences were present in spoken repetition accuracy where the older age group were more accurate than the younger age group. This was assumed to be due to the improved motor and cognitive skills that children gained with age (Davis & D'Amato, 2010). As significant differences were found in the ages of children for each of the two age groups used in Experiment Two, age was used as a covariate in this experiment, thus preventing examination across the two age groups. Although, using the exact age of the participants as a covariate lost the factor of age group in the analyses, the statistical tests that were conducted controlled for the variability between language groups on this factor so that any inferences drawn from the analyses regarding the factors of language group and neighbourhood density were more conclusive.

The neighbourhood density measures of the stimuli should only be relevant to the English monolingual group, as the bilingual and Cantonese monolinguals were predicted to have different words in the lexicon. Therefore, for the two comparisons made, the factor of age group would have only been directly relevant to the English monolinguals. For these reasons, losing the effect of age group was not problematic. Also, this factor has already been investigated in Experiment Two. As the factor of age led to significant differences in repetition accuracy, it appears that controlling for this factor and examining the effects of the other factors (language group and neighbourhood density) without biases, adds to the understanding of child language development more than if age group had been included. Since the effect of age group was examined in the previous chapter, the main discussion here will be on the effects of language group and neighbourhood density on repetition accuracy.

Table 7-26 summarizes the results of Comparison One which is the comparisons between words known at age 3 and non-words (including words not known until age 5). Those comparisons which were significant or marginally significant are coloured green and grey respectively.

Table 7-26. *Results from the experiment showing significant and non-significant effects when repetition accuracy was compared in words known at age 3 and non-words (including words not known until age 5). Cells in green indicate that the statistics for that entry were significant and those in red indicate that the statistics of that entry were not significant. Cells in grey are those that were marginally significant.*

Factors	**Comparison of HH, HL, LH, and LL within Word and Non-word**		**Comparison of HH, HL, LH, and LL between Word and Non-word**
	Word	**Non-word**	
Language and Neighbourhood Density Interaction	Significant for First-Order Neighbourhood Density	Not Significant	Significant for Low First-Order Neighbourhood Density and Language interaction, also for LH Second-Order Neighbourhood Density and Language Interaction
Main Effect of Neighbourhood Density	Not Significant	Significant for Second-Order Neighbourhood Density	Not Significant
Main Effect of Language	Significant	Significant	Significant

Table 7-27 summarizes the results of Comparison Two, which comprises the comparisons between words not known until age 5 and pseudo-words. Those comparisons that were significant or marginally significant are coloured green and grey respectively.

Table 7-27. *Results from the experiment showing significant and non-significant effects when repetition accuracy was compared in words not known until age 5 and pseudo-words. Cells in green indicate that the statistics for that entry were significant and those in red indicate that the statistics of that entry were not significant. Cells in grey are those that were marginally significant.*

Factors	**Comparison of HH, HL, LH, and LL within Word and Pseudo-word**		**Comparison of HH, HL, LH, and LL between Word and Pseudo-word**
	Word	**Pseudo-word**	
Language and Neighbourhood Density Interaction	Significant for Second-Order Neighbourhood Density	Significant for Second-Order Neighbourhood Density	Significant for LH and LL phone strings
Main Effect of Neighbourhood Density	Significant for First and Second-Order Neighbourhood Density	Significant for Second-Order Neighbourhood Density	Significant for High First-Order Neighbourhood Density and HL, LH and LL phone strings
Main Effect of Language	Significant	Significant	Significant

7.7.2.3 **Correlations between English Exposure and Repetition Accuracy**

Pearson's correlation tests conducted on cumulative English exposure (at home and at school) on Cantonese-English bilinguals' and Cantonese monolinguals' repetition accuracy of different phone string types illustrated very different effects between English exposure at home and at school.

Cumulative English exposure at home correlated with repetition accuracy in almost all of the phone strings apart from the 3HH, 5HH, 5LH and NonLL phone strings. On the other hand, cumulative English exposure at school only correlated with 3LL and 5LL phone strings. This shows that English exposure at home is a better predictor of repetition accuracy. However, in the case of LL words, English exposure at school can also be useful. The different types of phone string accuracies that are predicted by English exposure at home and at school show that the environment in which English is learnt can cause an effect on phone string processing.

7.7.3 *Evaluation of the Extended and Reduced Vocabulary Models*

7.7.3.1 **Language Group and Neighbourhood Density Interaction Effects**

Both the Extended and Reduced Vocabulary Models proposed predicts that there should be a language group and neighbourhood density interaction effect on the repetition of the stimuli.

7.7.3.1.1 Comparison One: Difference between words known at age 3 and non-words

For Comparison One (between words known at age 3 and the set of non-words), the predicted interaction effect was found for the within-word set (words known at age 3) analysis and also for the between-word and non-word analysis.

The result of the within-word set analysis showed that there was a significant interaction between language and first-order neighbourhood density, where the monolinguals' repetition performance was similar in the words with high and low first-order neighbourhood densities, whereas the bilinguals showed more variation between words with high and low first-order neighbourhood density. In particular, the repetition accuracy order of the language groups on words with low first-order neighbourhood density were as the Reduced Vocabulary Model had predicted, where the English monolinguals performed the best and the Cantonese monolinguals performed the worst. However, for the high first-order neighbourhood density words, it was the bilingual group that was the least accurate.

It thus appears that the high first-order neighbourhood density of the words known at age 3 can indicate a bilingual disadvantage in processing, which is not demonstrated in words with low first-order neighbourhood density. It is possible that the large number of neighbours in the words with high first-order neighbourhood density caused problems for the bilingual group as they have within-language and between-language neighbours, as proposed by the Extended Vocabulary Model. Therefore, the processing of these words may have to go through more lexical connections than when the same words are exposed to both groups of monolinguals. This in turn would affect processing speed and accuracy as there are more possibilities for interference in the lexical search when there are a larger number of connections.

The results from the between-word and non-word analysis showed that only a significant language and neighbourhood density effect was present for low first-order neighbourhood density and language interaction, and for LH second-order neighbourhood density and language interaction. For both interaction effects, it was found that the two monolingual groups did not differ much between their word-non-word accuracies, but the bilinguals showed a clear word advantage over the non-words.

This finding once again demonstrated a monolingual-bilingual difference in the repetition task, as illustrated earlier for the interaction between language and first-order neighbourhood density of words known at age 3. Looking at the interaction effect in more detail, it can be seen that the Cantonese monolingual phone string repetition advantage over the bilinguals only occurred for the non-words. For the word set, the order of accuracy of the language groups followed the predictions of the Reduced Vocabulary Model, where English monolinguals performed the best, followed by the bilinguals and finally the Cantonese monolinguals. The Cantonese-English bilinguals appear to demonstrate poorer non-word performance over words.

The monolingual-bilingual difference can once again be accounted for by the different processing strategies used by the language groups. The bilingual group was the only group who showed a word over non-word advantage, this could be because of all three language groups, the bilinguals would be more likely to accept new phone strings as possible word candidates as they have to learn vocabulary from two languages. Thus when a phone string is presented it is possible that bilinguals may want to acquire them into the lexicon, thus switching between lexical and sublexical processing as they are confused as to whether the presented phone string is a word or non-word. The act of acquiring a new phone string creates new lexical links in the lexicon, which could cause processing delay and also inaccuracies as the links are not completely formed. This explains why the bilinguals perform worse on the non-words.

Phone strings with low neighbourhood densities are the most problematic as they do not have many lexical connections, so their lexical processing takes longer and is less accurate. In the case of non-words with low neighbourhood densities, bilinguals would have to first check whether the presented stimulus is a word or non-word, and then further assess the phone string if it is identified as a non-word as they may want to acquire it into their lexicon. As these non-words have low neighbourhood densities, if they were to be acquired, then more lexical links would need to be created in the lexicon thus causing processing delay.

The within-word set and between-word and non-word analysis illustrated the language group and neighbourhood density interaction effect. This supports the predictions made by the Extended and Reduced Vocabulary Models. However the bilingual disadvantage (i.e. repetition accuracy the worse out of the three language groups) in these results goes against the predictions made by the Reduced Vocabulary Model; thus it is possible that the higher level of English exposure in the bilinguals over the Cantonese monolinguals does not provide a repetition advantage.

It can also be seen that in Comparison One, the set of non-words showed no language group and neighbourhood density interaction effect, which indicates that all three groups were processing these phone strings in the same way. This result rejects both of the Extended and Reduced Vocabulary Model predictions. It is possible that all three language groups were processing the pseudo-word within the non-words in this comparison sublexically, as predicted by the Generative Acquisition Hypothesis Processing Shift Model. As only a limited number of participants within the sample knew the words that were acquired by age 5, there may not have been enough power from them to induce the interaction effect that was predicted.

7.7.3.1.2 Comparison Two: Difference between words not known until age 5 and pseudo-words

For Comparison Two (between words not known until age 5 and the set of pseudo-words), the predicted interaction was found within word (words not known until age 5) and pseudo-word sets, and also for the between word and pseudo-word analysis. This supports the predictions made by both the Extended and Reduced Vocabulary Models.

However, when these interactions were examined more closely, it was found that order of performance between the three language groups were not in the order that the Reduced Vocabulary Model predicted (English monolinguals the best and Cantonese monolinguals the worse). For example, in the case of the word set, it was found the bilingual group was only more accurate than the Cantonese monolinguals for the LL words. For all the other word types, the bilinguals showed a processing disadvantage, being the least accurate of the three language groups. Similarly, for the pseudo-words, there was a bilingual disadvantage on non-word repetition accuracy compared to the Cantonese monolinguals. This poor accuracy by the bilinguals for the pseudo-words is the same as the one found in Comparison One for the non-word set. This can be explained by supposing bilinguals to be uncertain whether to acquire a new phone string into their lexicon or not, resulting in a state between lexical and sublexical processing.

An interesting finding from the experiment is that the Cantonese monolinguals demonstrated a reverse phone string set effect for the word and pseudo-word sets. For the word set, the Cantonese monolinguals were the most accurate in LL, followed by HL, HH and LH phone strings, whereas for the pseudo-words, the order was reversed. As the Cantonese monolinguals have some knowledge of English, it may well be that they are treating the words not known until age 5 as words and the pseudo-words as non-words, thus processing them lexically and sublexically respectively (based on the Generative hypothesis Hprocessing Shift Model). This explains why the repetition accuracy effect is reversed over this comparison.

The between-word and pseudo-word findings are slightly different from those found for the within-word and pseudo-word analysis. For this, a significant interaction effect was found for language and the LH and LL phone strings. For the LH phone strings, the bilinguals and the Cantonese monolinguals were less accurate in the word set than the non-word set. On the other hand, for the LL phone strings, all the children were less accurate on the LL non-words than words.

The difference between LH and LL phone strings demonstrated the importance of studying second-order neighbourhood density, as the direction of the word/non-word effects were reversed. As both LH and LL phone strings have a low number of first-order neighbours, their processing may rely on further lexical links, such as those in the second-order neighbours. LH phone strings have a larger number of second-order neighbours compared to LL phone strings, so there may be more interference in the processing of LH words (lexical processing) compared to LL words that have a limited number of neighbours. Sublexical processing on the other hand would have the reverse effect, as the high number of second-order neighbours in the LH non-words would actually aid processing and help children deal with words with these phoneme combinations. These ideas are proposed by the Generative Acquisition Hypothesis Processing Shift Model.

7.7.3.2 **Conclusion**

The prediction made by the Extended and Reduced Vocabulary Models that there should be a language group and neighbourhood density interaction effect is supported by the results of the analysis (except for the within non-word comparisons in Comparison One). This shows that the three language groups process the phone strings differently and the neighbourhood density of the phone strings also affects children in different ways depending on the languages(s) that they know.

The Extended Vocabulary Model explains this interaction effect by proposing that all three language groups have different lexicons, therefore they will treat the phone strings differently, such as their word/non-word status, and their neighbourhood density properties.

On the other hand, the Reduced Vocabulary Model explains this interaction effect as a result of the time the children had spent learning each language. Despite the interaction found, the Reduced Vocabulary Model is not fully supported because the prediction that English monolinguals would be the most accurate in the repetition test, followed by Cantonese-English bilinguals and then Cantonese monolinguals, was not held. In most of the comparisons, it was found that the bilingual group was the least accurate, especially for non-word sets. It thus appears that processing differences between the three language groups may not be due to language exposure.

Based on the findings from the repetition task, it thus appears that the Extended Vocabulary Model may be a better model in understanding processing differences between monolinguals and bilinguals than the Reduced Vocabulary Model. However, it was argued based on the phoneme inventories of English and Cantonese that there should not have been many neighbours between the two languages so the Cantonese-English bilingual group's performance should be similar to the English monolingual group's. As this was not the case it appears that there is an influence of Cantonese on the processing of English words.

7.7.3.3 Correlations between English Exposure and Repetition Accuracy

One prediction made by the Reduced Vocabulary Model is that English word processing is affected by English exposure, because the more time an individual spends learning English, the more English words they will know. This means processing lexically is more likely to occur than processing sublexically with length of exposure.

The results from the correlation analysis between cumulative English exposure in the Cantonese-English bilinguals and the Cantonese monolinguals supported this, as cumulative English exposure at home correlated with the repetition accuracies for most of the phone string types. Despite this, the correlation analysis between cumulative English at school and phone string repetition accuracy, produced only a correlation between LL words. This demonstrates that although English exposure is related to phone string processing, the environment in which the exposure takes place is influential on how processing is affected. It is possible that for the different environments, different English vocabularies are taught, hence the reason why English exposure at home and at school related to the repetition accuracies of different phone string types.

The results of the correlation analysis thus partially supports the ideas proposed by the Reduced Vocabulary Model, as not all English exposure (at home and at school) affects all the types of phone string processing.

7.7.4 *Evaluation of Parent and Child Language History Questionnaire Reliability*

It should be recalled that an extra feature of interest in this experiment was whether it was possible to determine children's language profiles by administering the language history questionnaire to the children as well as to their parents. The parent and child language history questionnaire reliability analysis found that only six items on the questionnaire had good or moderate ICC values. As this only constituted 15.38% of the items on the questionnaire, this showed that parent and child responses have very low reliability.

The reasons for the low reliability found between parent and child responses could be a result of the methodological problems with the language history questionnaire itself. Research has shown that designing and testing questionnaires on children is difficult and that much care is required in order to obtain good-quality results from children (Bell, 2007; Borgers et al., 2000). As children are sensitive to influences from adults, it is important that adults do not ask leading questions and that the types of questions asked are appropriate for the age group interviewed. As the language questionnaires were administered to the children by their parents, there may have been differences in the translation of the questions within each family, which would have affected the children's responses. Also, Borgers et al., (2000) recommended not to interview children younger than 4 years old as they are still in their preconceptual thought stage and their language development is not at the required level to give valid answers to the questions asked. In the case of the current experiment, there were children who were younger than 4 years old who completed the language history questionnaire, which could have affected the validity of the results.

Furthermore, the questions in the language history questionnaire involved concepts of time, which are complex for young children who have not developed the cognitive abilities to deal with such concepts (Siegler & Richards, 1979). Feedback from the parents regarding the difficulties of these questions in the questionnaire reinforced this.

Thus it is important to consider the questions and the way they are administered in the language history questionnaire to children in the future in order to obtain better quality results. Out of all the questions in the language history questionnaire, the questions on cumulative language exposure to English and Cantonese at home and at school were probably the ones that provided the best summary information: they reflect the amount of language exposure over development. One way to help children understand these questions better would be to provide visual aids, such as pie charts which could help children understand the concepts of percentage and allow them to show how much time they spend on each language. Thus, to improve on the language history questionnaire, further studies need to be conducted so that a more appropriate and effective questionnaire can be developed.

7.7.5 *Limitations and General Discussion*

It was argued that based on the interaction effects found between language group and neighbourhood density that the Extended Vocabulary Model was better than the Reduced Vocabulary Model in explaining processing differences between bilinguals and monolinguals.

The Extended Vocabulary Model takes into account that bilinguals have cross-over neighbourhood densities between their two languages, which is why they process phone strings differently from the monolinguals. It was argued that as English and Cantonese appeared to have very different phoneme inventories the two would not have many cross language neighbours to affect processing accuracies, so the bilinguals were predicted to not perform that differently from the English monolinguals. However this idea was not supported in the results. To further falsify the Extended Vocabulary Model, a neighbourhood density calculator that is able to calculate the number of neighbours a phone string has, in both English and Cantonese, would be useful in assessing whether cross-over neighbourhood density effects exist. In particular, such calculators should consider word age-of-acquisition for the two languages, because as argued in previous chapters, the number of words a child knows at a specific age will affect the neighbourhood density properties of words at that age.

Although the predictions of the Reduced Vocabulary Model were not supported in the repetition task, the correlation analysis between phone string accuracy and English exposure did partially support ideas from the model. It thus appears that in order to consider fully the words that exists within an individual's lexicon, as well as age-of-acquisition of words, language exposure is important (as this can determine the types of words learnt). As English exposure at home and at school correlated with different phone string accuracies, it would be interesting to obtain a list of English words that are learnt from the two environments. This way it is possible to assess the difference between the words that children are exposed to in the two environments and see which ones are more helpful for word processing.

In hindsight, as the results from the second experiment (Chapter 6) did not fully support the predictions made by the Generative Acquisition Hypothesis Processing Shift Model, it may have been a better idea to further test the differences between English monolinguals of different ages rather than to move on to examining bilinguals. If the results had been clearer cut for the monolinguals then the Generative Acquisition Hypothesis Processing Shift Model could have been adapted to better provide an explanation in understanding neighbourhood density effects on word and non-word processing in children. This way the Extended and Reduced Vocabulary Models may have given better predictions of how neighbourhood density effects of phone strings affect bilinguals, because these models use the Generative Acquisition Hypothesis Processing Model as a basis.

The experiment here faced many challenges, as it was hard to define the bilingual and Cantonese monolingual groups. Although it was assumed that the Cantonese monolinguals did not know any English, it was found from the language history questionnaire that they did have some knowledge of it, having been exposed to it. The definition of the language groups may therefore not have been very precise and could have affected the results because the Cantonese monolingual group actually comprise (low level) bilinguals. Interestingly, even though the Cantonese monolingual group are bilinguals, their performance still differed from the

Cantonese-English bilingual group in the experiment. In future experiments it is necessary to have an in-depth language profile of the participants, as the language levels within bilinguals can vary a lot.

The language history questionnaire was useful in assessing the amount of time each child spent learning English and Cantonese, and the cumulative English exposure responses were used for the correlational analysis. The reliability analysis between parents' and children's responses to the questionnaire showed many of the items in the question failed to reach excellent or good ICC values, implying that an improved methodology is required to obtain information about children's language development. As the language history questionnaire is important in assessing the language profiles of the children, better design and implementation is required so that more reliable answers can be obtained. As the definition of a bilingual is difficult and reliance is needed on their language profiles, the language history questionnaire needs to be tested to ensure that it is valid.

In summary, the findings of the experiment illustrated the processing differences between monolinguals and bilinguals on the stimuli presented, where English monolinguals performed better than the other two groups. These results are important as they help to improve tests conducted on children and raise issues which researchers need to take into account in experimental studies that look at early language development.

8 Chapter 8: A New Approach to the Development of Lexical Networks: The New Model

8.1 Conclusions

8.1.1 *Summary of Findings*

The aim of the thesis was to make progress on understanding the development of the human lexicon, in particular the changes that occur in early childhood. A model of language processing, Generative Acquisition Hypothesis Processing Shift Model, developed from Vitevitch and Luce (1999) was proposed to explain the processing differences between phone strings with different properties. The usage factors of phone strings (words and non-words) that were investigated in this thesis were word age-of-acquisition, word frequency and neighbourhood density. A particular focus was on the factor of neighbourhood density, where an extension to research in the literature was made by investigating the factor of second-order neighbourhood density (the number of neighbours calculated from a phone string's immediate neighbours).

In Chapter 3, a program was written that returned the number of valid first- and second-order neighbours from an inputted word list for children of a selected age, so that the neighbourhood density statistics obtained were appropriate for the age group selected. The results from the computational analyses were important as they provided the basis for the investigation of neighbourhood density and also helped to illustrate the way lexical connections are formed in early development, for instance why there are more words with low density neighbour words compared to words with high density neighbour in the lexicon in early development.

Using the data obtained in Computational Analyses One, a picture-naming task was devised to test pre-school children's responses to words (presented as pictures) with different first- and second-order neighbourhood densities (Chapter 4). Based on connectionist modellers' ideas, word neighbours can either inhibit retrieval (Lexical Competition Theory; Grainger & Jacobs, 1993) or facilitate it (Global Activation Theory; Grainger & Jacobs, 1996). As the majority of words in early lexical development have sparse neighbourhoods, as shown in the first computational analyses, the Global Activation Theory was argued to be a more appropriate theory in explaining neighbourhood density effects in lexical processing. The Global Activation Theory proposed that the word neighbours of the target word that are similar to the target, would not inhibit processing. Instead, they aid it by summing up all the activation of any phonemes that they share with the target word, and this helps individuals to retrieve the articulatory units (speech sounds) of the target word.

However, no significant neighbourhood density effects were found in the first experiment. This could have been because of methodological problems that occurred in Experiment One. Examples are the high demand the task made on children and the computational method used to obtain the stimuli which restricted the stimuli that were generated to monosyllabic words. The experiment thus failed to confirm hypotheses on how words in the lexicon are connected and how they can influence the way one another are processed.

To address the limitations of Computational Analyses One and Experiment One, a second set of computational analyses was conducted in which the neighbourhood density calculations were extended to multisyllabic words (Chapter 5). Furthermore, ideas on how changes from a non-word to a word happen in the lexicon and the effects this has on neighbourhood density were included.

The Generative Acquisition Hypothesis Processing Shift Model of word/non-word processing was proposed as an addition to Vitevitch and Luce's (1999) model to explain why word/non-word processing differences occur. The Generative Acquisition Hypothesis Processing Shift Model suggested that words are processed lexically, with the phonemes of the word chunked and processed as a whole unit using top-down analysis. In contrast, non-words were considered to be processed sublexically with the phonemes and phoneme chunks filtered up into short-term memory in a bottom-up fashion. As a result of the differences in the processing of words and non-words, neighbourhood density effects should also differ.

The Generative Acquisition Hypothesis Processing Shift Model argued that in the case of words, the Lexical Competition Theory provided a better explanation of the effects of neighbourhood density; high neighbourhood density words would be processed slower than words with low neighbourhood densities. The reason for this was because the neighbouring words in the lexicon caused lateral inhibition (competition between the nodes) so that a word with a lot of word neighbours would take longer and be less accurate when converted to speech. On the other hand, for non-words, if the Global Activation Theory provided a better explanation of the effects of neighbourhood density; high neighbourhood density words would be processed faster than non-words with low neighbourhood densities. In this case, non-words with a large number of neighbours aided processing because the phoneme chunks that they shared caused a greater summed activation level and helped the individual retrieve the articulatory units that they needed in order to produce the phonemes from the target non-word.

Computational Analyses Two calculated neighbourhood density properties for three sets of phone strings: words known at age 3, words not known until age 5 and pseudo-words. It was found that there were fewer monosyllabic words acquired at age 5 compared to age 3 and that the number of word neighbours for words known at age 3 was higher than those for words not known until age 5 and the pseudo-words.

From the results of these computational analyses it appeared that the neighbourhood density effects at age 5 were reduced relative to age 3. Therefore, the first computational analysis that only looked at monosyllabic words may actually have provided a better representation of how children's early lexicons develop, as children learn these words first. As multisyllabic words have fewer neighbours than do monosyllabic words, this would affect the neighbourhood density statistics in the second computational analysis.

The problems with the neighbourhood density effects at age 5 being reduced explains why not all the predicted neighbourhood density and age interaction effects were found in Experiment Two (Chapter 6). In Experiment Two, phone string repetition accuracy of two groups of children's (under age 5, and 5 and over) was tested on phone strings with different neighbourhood densities (as calculated from Computational Analyses Two).

No interactions were found between age group and first-order neighbourhood density nor were there any interactions between age group and second-order neighbourhood density within words and non-words; this applied to: 1) words known at age 3 and non-words (including those words acquired at age 5, as these are treated as non-words by children under age 5); and 2) words not known until age 5 and pseudo-words.

However, a main effect of age group was found across all comparisons (apart from when comparing phone string groups within words known at age 3), where the older age group was more accurate than the younger age group. This finding added to the problem of the neighbourhood density effects at age 5 being reduced, as it appears that there were also other factors that occurred when children get older. For example, it was argued that children in the older age group had more developed cognitive abilities (Davis & D'Amato, 2010), and phonological systems than the younger age group (Berry & Eisenson, 1956; Grunwell, 1982) for dealing with word/non-word processing. From these findings it thus appears that future experiments on child language development need to be conducted on younger children (those under age 5) before their lexicon and cognitive abilities become stable in order to better test out the Generative Acquisition Hypothesis Processing Shift Model.

As a clear effect of age group was present in Experiment Two, the exact ages of the participants were entered into the model as a covariate in Experiment

Three (Chapter 7) in order to account for individual differences. Since the exact age of the participants was entered as a covariate, the results obtained from Experiment Two and Three cannot be directly compared, as the two experiments investigated different factors. For Experiment Two, the focus of interest was seeing whether age of the participants and the neighbourhood density of phone strings had an effect on spoken repetition, whereas for Experiment Three, the focus of interest was seeing whether language group (English monolingual, Cantonese-English bilingual, Cantonese monolingual) and neighbourhood density of phone strings had an effect on spoken word performance.

As Experiment Two had only looked at the repetition accuracies of English monolingual children, the results only apply to this group. Since using a second language requires similar non-word to word changes that occur in English monolingual children's language development, it was important to see whether using a second language affected how English words and pseudo-words were produced. To ensure whether any differences between language groups were a result of the different words they have acquired in their lexicon, a group of Cantonese monolinguals was also tested in this experiment.

Two extensions to the Generative Acquisition Hypothesis Processing Shift Model were proposed to explain the processing differences between the three language groups; the Extended Vocabulary Model and the Reduced Vocabulary Model.

The Extended Vocabulary Model argues that phone string repetition accuracies should differ between all three language groups (English monolingual, Cantonese-English bilingual, Cantonese monolingual) because they each have different words in their lexicons. This subsequently affects the way they perceive the neighbourhood density properties of the stimuli presented. Monolinguals should have a lexicon that consists only of their first language, but bilinguals should have a shared lexicon between English and Cantonese. Thus there should be cross-over language neighbours between these two languages.

The Reduced Vocabulary Model, on the other hand, argues that the bilingual group should store the English and Cantonese lexicons in their overall lexicon separately so there should be no cross-over neighbourhood density effect. Word repetition should be only affected by the amount of time the children spent learning their language(s). The more time a child spends learning a language the more words they should be able to acquire into their lexicon. Therefore, bilingual children who have to share their time learning two languages would act more like phonologically delayed monolinguals.

The information regarding children's cumulative English exposure at home and at school was obtained from the language history questionnaire administered. This helped to evaluate the Reduced Vocabulary Model. The correlational analyses between these factors and the repetition accuracy of the phone string types showed that English exposure at home is useful in predicting the outcomes of eight of the phone string types, whereas English exposure at school was only able to predict two. Overall, language history information showed that caution should be exercised so as not to over-estimate the effects of language exposure, because not all exposure in different environments has the same effect.

The correlational analyses were only useful for looking at how English exposure can predict repetition accuracy but do not test whether there is a difference between the three language groups. The results from the repetition task helped to test this.

Significant interactions between language and neighbourhood density were found within words known at age 3 and 5, and the pseudo-words, thus supporting both the Extended and Reduced Vocabulary Models. A repeated finding from the interaction effect was that the Cantonese-English bilinguals demonstrated a word over non-word repetition accuracy advantage that was not present in the monolinguals. This was not an effect that was predicted by the Reduced Vocabulary Model. This model predicted that the Cantonese monolingual group should perform the worse because they should arguably not known English and treat all phone strings as non-words and process them sublexically.

The similar pattern shown by the two monolingual groups across words and non-words suggests that being monolingual overrides language/linguistic differences. The prediction that bilinguals would perform intermediately between the two monolingual groups was confirmed for words. However, non-word processing was affected in this group and there was a bilingual disadvantage for this task, showing that the use of two languages changed non-word processing markedly. One possible reason why there is a bilingual disadvantage, in particular in non-words when there is a language by neighbourhood density interaction, could be the effects of processing shifts that the bilingual group makes. Of the three groups, the bilingual group is the one that is most likely to treat a non-word as a potential phone string that needs to be acquired into their lexicon. Therefore they are more likely to be disrupted in processing a phone string lexically or sublexically. As argued in the Generative Acquisition Hypothesis Processing Shift Model, non-words are acquired into the lexicon using word repetition and contextual representation so that lexical links to the new word can be formed. It is thus possible that the partial formation of a lexical link (trying to convert a non-word to a word) causes processing difficulties because the individual is shifting between lexical and sublexical processing constantly until a stable link has been formed.

The results of the language history questionnaire showed that the Cantonese monolinguals group actually knew some English (they may have been exposed to it both at home and at school) so technically they are bilinguals. Yet, their performance was still more similar to that of the English monolinguals, unlike that of the group classified as Cantonese-English bilinguals. It thus appears that it may not be the amount of language exposure that causes processing differences because if this was the case then the bilingual group should have performed better than the Cantonese monolingual group because the language history questionnaire showed that the bilingual group learned both English and Cantonese at a younger age than the Cantonese monolinguals and were exposure to them more at school. It therefore appears that the initial language acquired by the individual is important in combination with how much practice they get trying to acquire words from another language. Both the bilinguals and Cantonese monolinguals acquired Cantonese as their first language, but the difference between the two groups was in the environment in which they operated (i.e. the bilinguals have to use English in the United Kingdom whereas the Cantonese monolinguals who live in Hong Kong do not). These environmental differences may have been the reason for the differences in performance between the two Cantonese groups.

With the possible language group effects that influence phone string repetition, it was difficult to draw conclusions regarding how neighbourhood density of words and non-words cause processing differences. Although the Generative Acquisition Hypothesis Processing Shift Model provided an explanation of how neighbourhood density effects are determined by the type of processing used (lexical or sublexical), the neighbourhood density effects found in the studies did not show any consistent trend and could not fully support the ideas proposed.

Although there was no fixed neighbourhood density set order in terms of accuracy, it was found throughout the experiments that the LL phone string set appeared to have special properties as it behaved differently from the other neighbourhood density sets. For example in both Experiments Two and Three, there appeared to be an LL word-non-word advantage-disadvantage depending on the other factors involved (age or language groups). The LL set was the only one that demonstrated this effect throughout the experiments, which indicated that the processing of this neighbourhood density type was either very different from the other sets or that the effects for this set were stronger than for the other groups, explaining why a consistent effect was found. One explanation put forward for this is that because the LL group had the lowest number of neighbours, children were the least familiar with the phoneme chunks that constituted these phone strings. Therefore, this set appeared novel and children were more likely to pay attention to them and to try harder to process them compared to other phone strings (Hoover et al., 2010).

The clear age and language effects that were found in the studies conducted made it difficult to determine fully the effects of neighbourhood density because the way processing was affected depended on the other factors involved. However, the studies conducted are influential as they demonstrate the complexity of language processing and the several factors that need to be jointly considered. This richness is inherent in the connectionist approaches discussed in the literature review of the thesis. As words are linked to one and another in the lexicon, it is not surprising that the processing of one can be influenced by many factors. In fact the results obtained in the experiments support the idea of mass connectivity in the lexicon and the fact that many usage factors, including all those considered here, work together to form the human lexicons.

8.1.2 *Review of the Generative Acquisition Hypothesis Processing Shift Model*

The findings in this thesis do not unambiguously support the Generative Acquisition Hypothesis Processing Shift Model put forward in this thesis. However, the results from the experiments have helped enhance our understanding of how children's lexicons develop over the early years. There are a number of key factors that need to be raised when understanding children's phone string processing abilities. Figure 8-1 presents the factors which need to be considered in turn in order to determine how a phone string will be processed.

Figure 8-1. Diagram illustrating factors that need to be considered in turn when trying to understand phone string processing in children.

First, the original language of the child is important because this determines the layout of the phonemes in the lexicon as different languages have different phoneme inventories, here English and Cantonese (Chan & Li, 2000). Second, the languages known by the child are important because monolinguals and bilinguals have practice at different forms of processing. For monolinguals, a lot of word acquisition happens in the early years of life, particularly around the vocabulary spurt (Ganger & Brent, 2004; Goldfield & Reznick, 1990; Mayor & Plunkett, 2010), yet this stabilises at around age 5, as demonstrated in Figure 3-5 of Computational Analyses One. For bilinguals on the other hand, as they have to spend time learning two languages, their lexicons are developed differently and this affects phone string processing. Changes may happen because they are unsure whether new phone strings should be acquired or not, thus there would be a lot of switching between lexical and sublexical processing. This is of particular importance when looking at the processing of non-words, as findings from the experiments have shown there is a bilingual disadvantage in non-word over word processing. For the processing of words, the bilingual group seem to follow the ideas in the Reduced Vocabulary Model, where the more time they spent learning English, the better their repetition accuracy.

The third factor is whether the child is bilingual. If the child is a bilingual, their language exposure to both languages needs to be checked because language exposure is associated with the processing of phone strings with certain neighbourhood density properties, as shown in the correlational analyses on the language history questionnaire.

Fourth, it is necessary to determine whether the phone string presented is perceived as a word or a non-word by the individual. To check this, age of the participant and their language exposure are needed to help establish whether the phone string has been acquired into the lexicon or not. Word age-of-acquisition databases would be useful for English monolinguals in this case, but for bilinguals this would be complicated as it would be necessary to assess the child's English levels in order to determine how developed their vocabularies were. Furthermore, phone string usage factors such as word frequency are important because when a phone string is presented once it does not have adult usage. Thus usage factor properties of the phone string for participants at specific ages can influence whether material is perceived as a true word or non-word.

Finally, after considering all the factors above, the neighbourhood density of the phone string can be calculated. For monolinguals this would involve, for example, determining whether the phone string is a word or a non-word, and then calculating neighbourhood density by relying on word age-of-acquisition statistics so that it is possible to estimate which words exist within the individuals' lexicon. For bilinguals this is more complicated, because the factors mentioned above need to be consider for both the bilinguals' first and second language before cross-over neighbourhood density properties can be calculated. By considering all the factors mentioned, more accurate predictions could be made on the processing accuracies of different children on a target phone string.

8.1.3 *Methodological Limitations and Future Work*

With the complexity of phone string processing as illustrated in this thesis, it is important that all the factors which could influence processing be taken into account, otherwise a small change in the lexicon could lead to large processing differences due to the mass connectivity of words within the lexicon.

As mentioned previously, since age is a factor that can influence phone string processing, testing of the usage factors of phone strings should be conducted on younger age groups so that the established cognitive abilities and phonological systems of a child do not wash out the effects of the usage factors. Furthermore, as language exposure is another factor that can influence the processing accuracies of specific phone strings, the language history questionnaire needs to be developed so that it is more reliable and can be completed by bilinguals as well as monolinguals of any language so that language profiles of children can be better established. Future work could then extend these tests to other language groups besides Cantonese to see if different languages produce different effects. Ultimately it should be possible to take all of these factors into account and develop a testing tool for spoken production in children to establish whether they have language disorders or whether they are simply influenced by the typical factors discussed.

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APPENDIX A

```
%runs in word list and removes words that aren't in the lexical
database

close all; %closes figures
clear all; %erase workspace
clc; %clear command window

[num txt RAW]=xlsread('0_9_freq',1); %read in word list from
different ages
Dimns=size(RAW);

[num1 txt1 RAW1]=xlsread('Lexical_database_tmp',1); %read in
lexical database
Dimns1=size(RAW1);

Grab=[];
y=1;
for i=2:Dimns;
    word=RAW{i,1};
    for a=1:Dimns1(1);
    if strcmp(word,RAW1{a,4});
        Grab{y}=word;
        y=y+1;
    else
    end
    end
end

file='Input_Words'; % change Excel file name accordingly
datafile=sprintf('%s_Excel_File', file); %used to specify Excel
file

xlswrite(datafile,Grab',1,'A1');
```

APPENDIX B

```
%select word list and obtain effective and rejected neighbours

close all; %closes figures
clear all; %erase workspace
clc; %clear command window

[num1 txt1 RAW1]=xlsread('Lexical_database_tmp',1); %read in
lexical database
[num3 txt3 RAW3]=xlsread('Word_list',1); %read in word list
Dimns3=size(RAW3);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% headings and title for Excel
file
filemain='0_9_list'; % change Excel file name accordingly
datafilemain=sprintf('%s_Excel_File', filemain); % specify Excel
file
T={'OVC Neighbours'};
T2={'Ph+/-1 Neighbours'};
G={'Effective'};
G2={'Rejected'};
H={'RN' 'CN' 'LN' 'RN' 'CN' 'LN' 'RN' 'CN' 'LN' 'RN' 'CN' 'LN'};
xlswrite(datafilemain,T,1,'A1'); %write to Excel file
xlswrite(datafilemain,T2,1,'G1');
xlswrite(datafilemain,G,1,'A2');
xlswrite(datafilemain,G,1,'G2');
xlswrite(datafilemain,G2,1,'D2');
xlswrite(datafilemain,G2,1,'J2');
xlswrite(datafilemain,H,1,'A3');

for z=1:Dimns3; %runs through word list
    word=RAW3{z,1}; %input target word

age=2; %change according to condition
Dimns=size(RAW1);


chck=0;

for i=1:Dimns(1);

   if strcmp(word,RAW1{i,4})
       Grab_code={RAW1{i,6:14}};
       chck=1;
    break; %break loop when match word and note i which gives the
row

   end
end

if chck==1,

z
Grab_code
```

```
xlswrite('Neighbourhood_tmp',Grab_code,'AC22:AK22'); %write into
neighbourhood database
[num txt RAW]=xlsread('Neighbourhood_tmp',1); %read in
neighbourhood database
c=num2str(z+3);

%First lot
st=26;
fn=38;
XLSAmain=sprintf('A%s', c);
XLSBmain=sprintf('D%s', c);
[RAW RAW1 ret e2 r2 e2num r2num]=
read_write_data3(RAW,st,fn,age,RAW1,Dimns,datafilemain,XLSAmain,XL
SBmain); %ret 1 for neighbours 0 for none

%Second lot
st=26;
fn=39;
XLSAmain=sprintf('B%s', c);
XLSBmain=sprintf('E%s', c);
[RAW RAW1 ret e2 r2 e2num r2num]=
read_write_data3(RAW,st,fn,age,RAW1,Dimns,datafilemain,XLSAmain,XL
SBmain); %ret 1 for neighbours 0 for none

%Third lot
st=26;
fn=40;
XLSA='C4';
XLSB='F4';
XLSAmain=sprintf('C%s', c);
XLSBmain=sprintf('F%s', c);
[RAW RAW1 ret e2 r2 e2num r2num]=
read_write_data3(RAW,st,fn,age,RAW1,Dimns,datafilemain,XLSAmain,XL
SBmain); %ret 1 for neighbours 0 for none

%Fourth lot
st=26;
fn=41;
XLSAmain=sprintf('G%s', c);
XLSBmain=sprintf('J%s', c);
[RAW RAW1 ret e2 r2 e2num r2num]=
read_write_data3(RAW,st,fn,age,RAW1,Dimns,datafilemain,XLSAmain,XL
SBmain); %ret 1 for neighbours 0 for none

%Fifth lot
st=26;
fn=42;
XLSAmain=sprintf('H%s', c);
XLSBmain=sprintf('K%s', c);
[RAW RAW1 ret e2 r2 e2num r2num]=
read_write_data3(RAW,st,fn,age,RAW1,Dimns,datafilemain,XLSAmain,XL
SBmain); %ret 1 for neighbours 0 for none

%Sixth lot
st=26;
fn=43;
XLSAmain=sprintf('I%s', c);
XLSBmain=sprintf('L%s', c);
```

```
[RAW RAW1 ret e2 r2 e2num r2num]=
read_write_data3(RAW,st,fn,age,RAW1,Dimns,datafilemain,XLSAmain,XL
SBmain); %ret 1 for neighbours 0 for none

end
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
function [RAW RAW1 ret e2 r2 e2num r2num]=
read_write_data3(RAW,st,fn,age,RAW1,Dimns,datafilemain,XLSAmain,XL
SBmain);

fcol=RAW{st,fn};

if fcol >=1,
for i=27:27+fcol-1,
    OVCCN{i-st}=RAW{i,fn};
end


r2=[];
e2=[];
xx=1;

Dims2=size(OVCCN);
for a=1:fcol %loop through neighbours
    for i=1:Dimns(1);
          if strcmp(OVCCN{a},RAW1{i,4});
             Grab_age{xx}=RAW1{i,35};

    break; %break loop when match word and note i which gives the
row
          end
    end
        for rs=length(r2)+1;
            es=length(e2)+1;
            if
strcmp(Grab_age{xx},'Abs')||Grab_age{xx}>=age,%determines if word
is known by a child or not
            r2{rs}=OVCCN{a};
            else
            e2{es}=OVCCN{a};
            end


    end
end


ret=1;
else

    ret=0;
    r2=[];
    e2=[];

end

e2num=length(e2);
```

```
r2num=length(r2);
xlswrite(datafilemain,e2num,1,XLSAmain);
xlswrite(datafilemain,r2num,1,XLSBmain);

end
```

APPENDIX C

```
%selects word and obtains strings of effective neighbours

close all; %closes figures
clear all; %erase workspace
clc; %clear command window
neigh=[];

[num1 txt1 RAW1]=xlsread('Lexical_database_tmp',1); %read in
lexical database
[num3 txt3 RAW3]=xlsread('Word_list',1); %read in word list
Dimns3=size(RAW3);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% headings and title for Excel
file
filemain='2_OVC_RN'; % change Excel file name accordingly
datafilemain=sprintf('%s_Excel_File', filemain); % specify Excel
file

for z=1:Dimns3; %runs through word list
    word=RAW3{z,1}; %input target word

age=2; %change according to condition
Dimns=size(RAW1);

chck=0;

for i=1:Dimns(1);

   if strcmp(word,RAW1{i,4})
       Grab_code={RAW1{i,6:14}};
       chck=1;
    break; %break loop when match word and note i which gives the
row
   end
end

if chck==1,

z
Grab_code

xlswrite('Neighbourhood_tmp',Grab_code,'AC22:AK22'); %write into
neighbourhood database
[num txt RAW]=xlsread('Neighbourhood_tmp',1); %read in
neighbourhood database

%First lot
st=26;
fn=39; % change accordingly depending on neighbourhood metric
category
[RAW RAW1 ret e2 r2 neigh]=
read_write_data_freq(RAW,st,fn,age,RAW1,Dimns,neigh); %ret 1 for
neighbors 0 for none
```

```
    end
    end

    xlswrite(datafilemain,neigh',1, 'A1');
```

APPENDIX D

List of words acquired by age 3, used in Experiment One. Those marked with an asterisk are words which also appear in the BPVS test.

HH	HL	LH	LL
tear	rain	cut	rope
night	deer	horse	sun
coat	door	horn	shell
ball	bee*	lamp	duck
tie	lock	cow*	phone
kite	bike	bird	cards
boat*	cat	boot	kick
hat	pie	doll	key
bear	bed	dogs	ski
bone	plane	hook	cake
tea	gold	train	truck
eye	gate*	bib	drum*
lamb	hand*	bag	bridge
comb	shirt	cap	fan
hill	pen	car	tree
wall	clock	house	box
ear	bread	owl	cheese
chair	rose	pig	beach
bell	book	lights	snake*
ring	watch	toast	egg

APPENDIX E

```
%selects word and obtains word frequency

close all; %closes figures
clear all; %erase workspace
clc; %clear command window
freq=[];


[num1 txt1 RAW1]=xlsread('Lexical_database_tmp',1); %read in
lexical database
[num3 txt3 RAW3]=xlsread('5_neigh_list',1); %read in word list
(change accordingly)
Dimns3=size(RAW3);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% headings and title for Excel
file
filemain='5_neigh_list_freq'; % change Excel file name accordingly
datafilemain=sprintf('%s_Excel_File', filemain); %used to specify
Excel file


for z=1:Dimns3; %runs through word list
    word=RAW3{z,1}; %input target word

Dimns=size(RAW1);


chck=0;

for i=1:Dimns(1);

   if strcmp(word,RAW1{i,4})
       Grab_code={RAW1{i,32}}; %grabs word frequency
       chck=1;
       break; %break loop when match word and note i which gives
the row

   end

end

if chck==1,


end

z
fq=Grab_code{1};
freq{z}=fq;

end

xlswrite(datafilemain,freq',1, 'A1');
```

APPENDIX F

The table on the next page shows the phonetic transcriptions of the phone strings using SAMPA coding obtained from Computational Analyses Two (Chapter 5) and used in Experiment Two (Chapter 6) and Three (Chapter 7).

	Age 3 High		*Age 3 Low*		*Age 5 High*		*Age 5 Low*		*Non-word High (based on 3 years)*		*Non-word Low (based on 3 years)*		*Non-word High (based on 5 years)*		*Non-word Low (based on 5 years)*	
Second Neighbour Low	*beat*	*b i: t*	*class*	*k l A: s*	*hell*	*h e l*	*chance*	*tS A: n s*	*nien*	*n I@ n*	*shind*	*S I n d*	*nien*	*n I@ n*	*wruiff*	*r u: I f*
	eye	*aI*	*pond*	*p Q n d*	*cell*	*s e l*	*pleased*	*p l i: z d*	*rhatch*	*r { tS*	*wruiff*	*r u: I f*	*koom*	*k u: m*	*shind*	*S I n d*
	die	*d aI*	*spell*	*s p e l*	*raise*	*r eI z*	*screen*	*s k r i: n*	*urse*	*3: s*	*sarms*	*s A: m z*	*rhatch*	*r { tS*	*drose*	*d r @U s*
	bar	*b A:*	*fish*	*f I S*	*aim*	*eI m*	*joined*	*dZ OI n d*	*jip*	*dZ I p*	*drose*	*d r @U s*	*urse*	*3: s*	*freace*	*f r i: s*
	low	*l @U*	*bank*	*b { N k*	*tin*	*t I n*	*twice*	*t w aI s*	*koom*	*k u: m*	*freace*	*f r i: s*	*jip*	*dZ I p*	*sarms*	*s A: m z*
	knee	*n i:*	*brain*	*b r eI n*	*pit*	*p I t*	*drove*	*d r @U v*	*sciew*	*s j u:*	*bute*	*b j u: t*	*ghart*	*g A: t*	*bute*	*b j u: t*
Second Neighbour High	*eh*	*eI*	*coach*	*k @U tS*	*kit*	*k I t*	*blame*	*b l eI m*	*ghart*	*g A: t*	*jobe*	*dZ @U b*	*sciew*	*s j u:*	*twot*	*t w Q t*
	row	*r @U*	*gold*	*g @U l d*	*lane*	*l eI n*	*grant*	*g r A: n t*	*phurl*	*f 3: l*	*twot*	*t w Q t*	*bauche*	*b O: tS*	*smiel*	*s m i: l*
	sea	*s i:*	*bread*	*b r e d*	*add*	*{ d*	*split*	*s p l I t*	*bauche*	*b O: tS*	*smiel*	*s m i: l*	*phurl*	*f 3: l*	*twea*	*t w I@*
	bay	*b eI*	*game*	*g eI m*	*rare*	*r e@*	*truth*	*t r u: T*	*zar*	*z @*	*twea*	*t w I@*	*zar*	*z @*	*rale*	*r aU l*
	ho	*h @U*	*pink*	*p I N k*	*wore*	*w O:*	*reached*	*r i: tS t*	*sha*	*S {*	*gork*	*g O: k*	*sha*	*S {*	*gork*	*g O: k*
	owe	*@U*	*thin*	*T I n*	*fee*	*f O:*	*ninth*	*n aI n T*	*wret*	*r e t*	*rale*	*r aU l*	*wret*	*r e t*	*jobe*	*dZ @U b*

APPENDIX G

Independent *t*-tests comparing phone string sets known at age 3 and non-words (including those words not known until age 5).

	Phone String Sets	***t***	***df***	***p***
First-Order Neighbour-hood Density	WordHH-NonHH	.191	18	.851 (equal variances not assumed)
	WordHL-NonHL	-.414	18	.684 (equal variances not assumed)
	WordLH-NonLH	.191	18	.851 (equal variances not assumed)
	WordLL-NonLL	1.311	14	.211 (equal variances not assumed)
Second-Order Neighbour-hood Density	WordHH-NonHH	-.607	17	.551 (equal variances not assumed)
	WordHL-NonHL	2.083	19	.051 (equal variances not assumed)
	WordLH-NonLH	-1.527	17	.144 (equal variances not assumed)
	WordLL-NonLL	.247	22	.807

Independent *t*-tests comparing phone string sets not known until age 5 and pseudo-words. Those marked with an asterisk were significant.

	Phone String Sets	***t***	***df***	***p***
First-Order Neighbour-hood Density	WordHH-NonHH	3.609	17	.002* (equal variances not assumed)
	WordHL-NonHL	5.249	16	< .001* (equal variances not assumed)
	WordLH-NonLH	-5.917	13	< .001* (equal variances not assumed)
	WordLL-NonLL	-2.006	22	.057
Second-Order Neighbour-hood Density	WordHH-NonHH	3.547	22	.002* (equal variances not assumed)
	WordHL-NonHL	9.095	22	< .001* (equal variances not assumed)
	WordLH-NonLH	-8.554	16	< .001* (equal variances not assumed)
	WordLL-NonLL	-2.364	22	.027* (equal variances not assumed)

APPENDIX H

Please provide your contact information below

Name (Parent):

Name (Child):

Email:

Please answer the following questions about your child to the best of your knowledge

1. Age:
2. Sex: Male / Female
3. List the languages in order of proficiency (most proficient first):
4. Your child's country of origin
5. How long has your child been in the UK?
6. Write in the box the age at which your child first learned each language in terms of speaking, reading, and writing, and the number of years you have spent learning each language.

Language	Age first learned the language			Number of years spent learning (cumulative)
	Speaking	Reading	Writing	
English				
Cantonese				

7. Write in the box the age at which your child started to learn each language in any or all of the following situations (if only one situation is relevant for one language, provide age information for only that situation).

Language	At home	At school	After immigrating to the country where spoken	At informal settings (e.g. from nannies, or friends)	Through software (e.g. Rosetta Stone)
English					
Cantonese					

8. Write down the name of the language(s) used by your child's teachers for general instruction (e.g. history, math, science) at each schooling level. If you switched language within a given school level, write a note such as "switched from X language to Y language at Grade Y".

   Primary/Elementary School:

   Secondary/Middle School:

9. Estimate, in terms of hours per day, how often your child is currently engaged in the following activities for each language you know. If they are not currently engaged in an activity using that language, write down "0".

Activities	Language: English	Language: Cantonese
Listen to Radio/ Watching TV:	(hrs)	(hrs)
Reading for fun:	(hrs)	(hrs)
Reading for work/school:	(hrs)	(hrs)
Reading on the Internet:	(hrs)	(hrs)
Writing emails to friends:	(hrs)	(hrs)
Writing for work/school:	(hrs)	(hrs)

10. Estimate, in terms of hours per day, how often your child speaks these languages with the following people.

Language	Family members	Friends	Classmates
English			
Cantonese			

11. For each year of your child's life, please estimate in percentage how much of each language is spoken in each of the environments:

Ages (years)	English		Cantonese	
	At Home	At School/Preschool/ Daycare	At Home	At School/Preschool /Daycare
0-1				
1-2				
2-3				
3-4				
4-5				
5-6				
6-7				
7-8				
8-9				
9-10				
10-11				
11-12				

APPENDIX I

Agreement (per questionnaire item) between parent and child responses to the language history questionnaire as indicated by intraclass correlation coefficients (ICC)

Item	ICC
'Are you better at speaking English or Cantonese?' (Proficiency)	0.182
'At what age did you learn to speak English?' (English Speaking)	0.164
'At what age did you learn to read English?' (English Reading)	0.118
'At what age did you learn to write English?' (English Writing)	-0.205
'At what age did you learn to speak Cantonese?' (Cantonese Speaking)	0.072
'At what age did you learn to read Cantonese?' (Cantonese Reading)	0.082
'At what age did you learn to write Cantonese?' (Cantonese Writing)	-0.210
'At what age did you start to learn English at home?' (English Home)	0.049
'At what age did you start to learn English in school?' (English School)	-0.035

'At what age did you start to learn English after immigrating to the country where English is spoken?' (English after immigrating)	N/A
'At what age did you start to learn English in informal settings (e.g. from nannies, or friends)?' (English informal)	0.712
'At what age did you start to learn English through software?' (English software)	N/A
'At what age did you start to learn Cantonese at home?' (Cantonese Home)	0.009
'At what age did you start to learn Cantonese in school?' (Cantonese School)	-0.092
'At what age did you start to learn Cantonese after immigrating to the country where Cantonese is spoken?' (Cantonese after immigrating)	N/A
'At what age did you start to learn Cantonese in informal settings (e.g. from nannies, or friends)?' (Cantonese informal)	0.488
'At what age did you start to learn Cantonese through software?' (Cantonese software)	N/A
'How many hours a day do you listen to radio/watch TV in English?' (English Radio and TV)	0.070
'How many hours a day do you read English for fun?' (English Reading for Fun)	0.400

‘How many hours a day do you read English for school?’ (English Reading for School)	0.178
‘How many hours a day do you read English on the internet?’ (English Reading on the Internet)	-0.023
‘How many hours a day do you write English emails to friends?’ (English Writing Emails)	0.000
‘How many hours a day do you write in English for work/school?’ (English Writing for School)	-0.128
‘How many hours a day do you listen to radio/watch TV in Cantonese?’ (Cantonese Radio and TV)	0.172
‘How many hours a day do you read Cantonese for fun?’ (Cantonese Reading for Fun)	-0.181
‘How many hours a day do you read Cantonese for school?’ (Cantonese Reading for School)	0.170
‘How many hours a day do you read Cantonese on the internet?’ (Cantonese Reading on the Internet)	0.018
‘How many hours a day do you write Cantonese emails to friends?’ (Cantonese Writing Emails)	N/A
‘How many hours a day do you write in Cantonese for work/school?’ (Cantonese Writing for School)	-0.097
‘How many hours a day do you talk in English to your family?’ (English Family)	0.248
‘How many hours a day do you talk in English to your friends?’ (English Friends)	-0.049

'How many hours a day do you talk in English to your classmates?' (English Classmates)	0.060
'How many hours a day do you talk in Cantonese to your family?' (Cantonese Family)	0.273
'How many hours a day do you talk in Cantonese to your friends?' (Cantonese Friends)	-0.079
'How many hours a day do you talk in Cantonese to your classmates?' (Cantonese Classmates)	-0.487
'For each year of your life, estimate how much in percentage you speak English at home' (Cumulative English Exposed at Home)	0.471
'For each year of your life, estimate how much in percentage you speak English at school' (Cumulative English Exposed at School)	0.744
'For each year of your life, estimate how much in percentage you speak Cantonese at home' (Cumulative Cantonese Exposed at Home)	0.742
'For each year of your life, estimate how much in percentage you speak Cantonese at school' (Cumulative Cantonese Exposed at School)	0.681