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Speech perception and phonological short-term memory capacity in language impairment: Preliminary evidence from adolescents with SLI and ASD

Running Head: Speech perception and STM in language impairment

KEY WORDS: language disorders, specific language impairment, autism spectrum disorders, nonword repetition tasks, working memory, speech perception

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Abstract

Background: The cognitive bases of language impairment in specific language impairment (SLI) and autism spectrum disorders (ASD) were investigated in a novel nonword comparison task which manipulated phonological short term memory (PSTM) and speech perception, both implicated in poor nonword repetition.

Aims: This study aimed to investigate the contributions of PSTM and speech perception in nonword processing and whether individuals with SLI and ASD plus language impairment (ALI) show similar or different patterns of deficit in these cognitive processes.

Method & Procedures: Three groups of adolescents (aged 14 to 17), 14 with SLI, 16 with ALI, and 17 age and nonverbal IQ matched typically developing (TD) controls, made speeded discriminations between nonword pairs. Stimuli varied in PSTM load (2- or 4-syllables) and speech perception load (mismatches on a word-initial or word-medial segment).

Outcomes & Results: Reaction times showed effects of both nonword length and mismatch position and these factors interacted: 4-syllable and word-initial mismatch stimuli resulted in the slowest decisions. Individuals with language impairment showed the same pattern of performance as those with typical development in the reaction time data. A marginal interaction between group and item length was driven by the SLI and ALI groups being less accurate with long items than short ones, a difference not found in the TD group.

Conclusions: Nonword discrimination suggests that there are similarities and differences between adolescents with SLI and ALI and their TD peers. Reaction times appear to be affected by increasing PSTM and speech perception loads in a similar way. However, there was some, albeit weaker, evidence that adolescents with SLI and ALI are less accurate than TD individuals, with both showing an effect of PSTM load. This may indicate, at some level, the processing substrate supporting both PSTM and speech perception may be intact in

adolescents with SLI and ALI , but also in both there may be impaired access to PSTM resources.

What This Paper Adds

There is evidence that the underlying causes of poor nonword repetition may be different in different developmental disorders associated with language impairment, such as specific language impairment (SLI) and autism spectrum disorders (ASD). Understanding the different possible causes of poor nonword repetition is complicated because it relies on intact speech perception and speech output, and phonological short-term memory (PSTM) and it is not possible to tease these processes apart within conventional nonword repetition tasks. The present study uses a new nonword discrimination (NWD) task which simultaneously manipulates PSTM and speech perception load but does not require any speech output. Results showed reaction times were affected by increasing PSTM and speech perception loads in a similar way in SLI, ASD plus language impairment (ALI) and in TD individuals. However, there was some, albeit weaker, evidence that adolescents with SLI and ALI were less accurate than TD individuals, with an effect of PSTM load in both groups. Adolescents with SLI and ALI showed a similar pattern of performance which may indicate, at some level, the processing substrate supporting both PSTM and speech perception is intact, but there may also be impaired access to PSTM resources.

Introduction

The challenge of understanding the nature of language impairment requires both careful consideration of the range of developmental disorders that are associated with language deficits and the cognitive basis of poor language ability. Methodological approaches that address both of these issues can help us meet this challenge. Direct comparisons between different disorders allow us to ask if language presentation is the same in different patterns of atypical development. Probing the nature of the impairment requires methodological approaches that address the cognitive processes which underpin surface behaviours. Here we attempt to combine these approaches to investigate the possible cognitive bases of language impairment in specific language impairment (SLI) and autism spectrum disorders (ASD).

SLI and ASD are common developmental disorders associated with language impairment. Where structural language abilities (phonology, semantics, syntax and morphology) have been the focus of investigations into SLI (for a review see Leonard, 1998), pragmatic impairments have driven research into language and communication in ASD, as difficulties in this area are almost universal and found regardless of level of intellectual functioning (Tager-Flusberg, Lord & Paul, 2005). Structural language impairments are associated with ASD (for a review see, Tager-Flusberg, Lord & Paul, 2005), but understanding the nature of these language deficits is complicated by the great heterogeneity of language and cognitive abilities within this population. Epidemiological studies indicate between a quarter and a half of children with an ASD have intellectual disabilities (Baird et al., 2006; Chakrabarti & Fombonne, 2001, 2005; Keen & Ward, 2004) and language impairment could be seen as the result of a general lowering of intellectual functioning. However, recently, Tager-Flusberg and colleagues (Kjelgaard & Tager-Flusberg, 2001; Roberts et al. 2004) have identified an ASD subgroup which presents with language impairment in the context of nonverbal skills within the average range (Autistic Language Impairment: henceforth, ALI). This psychometric profile typical of SLI, invites the comparison between SLI and ALI .

Deficits can present at all structural levels of language in SLI, but production of grammatical morphology appears to be disproportionately impaired relative to other areas of language and these deficits are a reliable clinical marker for SLI (Rice et al., 2000). For example, English speaking children with SLI omit morphemes marking tense, such as third-person singular –s and past tense –ed, to a greater degree than their general delay in language acquisition. Children with ALI show similar high rates of omission of third-person singular and past tense morphemes (Roberts et al., 2004). A second clinical marker for SLI that has received a lot of attention is nonword repetition (Bishop, North, & Donlan, 1996). In nonword repetition individuals repeat nonsense words consisting of different numbers of syllables and it is argued to be a relatively pure measure of phonological short-term memory (PSTM) (Gathercole & Baddeley, 1989). By storing verbal input temporarily, PSTM allows other cognitive tasks such as verbal comprehension to take place and allows phonological information, such as word form representations, to be transferred to long-term memory (Montgomery, 2003). The importance of nonword repetition in understanding the aetiology of SLI has been underscored by recent evidence that poor nonword repetition is strongly associated with a quantitative trait locus on chromosome 16q (SLIC, 2004).

Nonword repetition also appears to be weak in children with ASD; although they may show less impairment than those with SLI. Kjelgaard and Tager-Flusberg (2001) reported that children with ALI had nonword repetition scores more than one standard deviation below the mean and although a group with ASD but no language impairment showed nonword repetition within the average range, the difference between the groups was not significant. Botting and Conti-Ramsden (2003) compared nonword repetition in children with SLI and those with ASD and found that those with SLI performed more poorly than the children with ASD. However, nonword repetition could not distinguish between SLI and ASD children with an accuracy of 70% or greater. While problems with nonword repetition are common to SLI and ASD the underlying cause of this poor performance may differ in these disorders. Bishop et al. (2004) studied nonword repetition in probands with ASD and their first-degree relatives. They found the expected poor nonword repetition in the probands but not in their parents and siblings, indicating that the deficit was not heritable. This contrasts with the findings for SLI where first-degree relatives present with lower nonword repetition scores than controls (Bishop et al., 1996).

To understand the different possible causes of poor nonword repetition the cognitive bases of the task need to be addressed. Nonword repetition is taken to index PSTM, but is a complex task which engages a number of cognitive processes. At a minimum it relies on intact speech perception and speech output, as well as PSTM. In theory any of these processes may be impaired leading to poor nonword repetition. Alternative explanations in terms of speech output deficits have been questioned because children with SLI do not differ from language-age controls in their articulation latency or rate of articulation (Gathercole & Baddeley, 1990; Montgomery, 1995). But, there is evidence to suggest that speech output factors influence performance in nonword repetition. For example, nonword repetition scores correlate significantly with articulation rates in 4-year-old children (Gathercole et al., 1999) and children's ability to repeat real words and nonwords improves significantly between the ages of 3 and 7 years (Vance, Stackhouse, & Wells, 2005). Evidence for speech perception deficits in SLI is mixed (for review see Ellis Weismer, 2005). Explanations of poor nonword repetition in terms of speech perceptual deficits have been rejected on the basis that children with SLI are reported to be able to discriminate between nonwords that differ by a single phonetic feature as well as nonverbal mental-age and language-age controls (Gathercole &

Baddeley, 1990). In contrast, Montgomery (1995) found differences between children with SLI and language-age controls in nonword discrimination, most clearly for four syllable nonwords. Morton and Schwartz (2003) did not replicate this finding. However, the conflicting results may be explained by differences in the stimuli; where Montgomery's stimuli differed by single phonemes, Morton and Schwartz's stimuli differed in stress pattern, which may have been easier for children with SLI to discriminate.

Nonword repetition combines, and so potentially conflates, these different processing demands, and so if individuals with SLI and ASD present with poor nonword repetition it is not possible to say which of these processes or combination of processes are impaired without measuring them independently. Such an approach would allow investigation of associations between different processes but causal relationships could only be inferred. The aim of this study was to evaluate possible causal relationships between PSTM and speech perceptual factors by directly manipulating them in a nonword processing task which did not involve an output component. This was achieved using a nonword discrimination task that, unlike Montgomery (1995) and Morton and Schwartz (2003), varied both PSTM and speech perception load. PSTM load was varied by by manipulating the length of stimuli (2- and 4-syllable nonwords are used) as in nonword repetition. Speech perception load was varied by manipulating the discriminability of nonwords. Single phonetic feature differences were used to maximise the difficulty of the discrimination and an additional speech perception load was added by varying the position of the mismatch in the nonword. Evidence from mispronunciation detection suggests that individuals' ability to detect mispronunciations depends on where the deviation occurs in the word. Adult listeners are slower to detect word-initial deviations than word-medial or final ones (for a review see Donselaar, 1996). Walley and Metsala (1990) found some evidence for differences in attention to word-initial as opposed to non-initial acoustic-phonetic information in children's and adults' reaction times during mispronunciation detection, which may suggest this contrast is sensitive to developmental differences in speech processing. Thus, manipulating the position of the deviating segment between mismatching pairs of nonwords may vary the difficulty of the discrimination and so the speech perception load. In the nonword discrimination task, listeners were presented with pairs of nonwords, differing either word initially or medially, and required to make a speeded same/different judgement. Performance on this nonword discrimination task (NDW) was expected to depend on the locus on an individual's processing deficit. An individual with a PSTM deficit would be expected to show relatively slower responses and be less accurate to 4-syllable pairs than 2-syllable pairs than individuals with intact PSTM. An individual with a speech perception deficit may be less able to use acoustic-phonetic information early in a word to facilitate discrimination and so show a relatively smaller difference in their response to initial and medial mismatches. This experimental approach to the possible cognitive bases of language impairment was complemented by comparisons between different disorders associated with language deficits, SLI and ALI, which allowed us to consider two related questions. What are the contributions of PSTM and speech perceptual factors in nonword processing? Do individuals with SLI and ALI show similar or different patterns of deficit in these cognitive processes?

Methods

Participants

The study investigated two clinical populations – adolescents with SLI and high-functioning adolescents with ASD with a language impairment (ALI). Twenty-seven adolescents with SLI or ALI were selected from a cohort of children with Special Educational Needs who had been assessed during the Special Needs and Autism Project (SNAP; Baird et al., 2006). A diagnosis of autism was made on the basis of ICD-10 (WHO, 1993) criteria using the Autism Diagnostic Interview-Revised (Lord et al. 1994) Autism Diagnostic

Observation Schedule -Generic (Lord et al., 2000), and additional information from locally-based assessment and information from schools (full details of the diagnostic process are available in Baird et al. 2006). Participants were categorised as being language impaired if there was a discrepancy between their language abilities, as measured by the Clinical Evaluation of Language Fundamentals-3rd Edition UK (CELF-3UK; Semel, Wiig, & Secord, 2000), and their non-verbal IQ scores, as measured by the Wechsler Intelligence Scale for Children-III (WISC-III; Wechsler, 1992). The language impairment was defined as a CELF-3UK Receptive, Expressive or Total Language standard score of 77 or below, while the normal nonverbal IQ was defined as a WISC-III Performance IQ or the Perceptual Organisational Index standard score of 80 or above. Overall 16 adolescents with ALI and ten with SLI were recruited from the SNAP cohort. The participants' language and non-verbal abilities assessed for SNAP, used to establish the groups for this study, were confirmed by retested using British Picture Vocabulary Scale – II (BPVS-II; Dunn et al., 1997), selected subtests from the CELF-3UK (Concepts and Directions (CD) and Recalling Sentences (RS)) and the WISC-III (Picture Arrangement (PA) and Block Design (BD)). Participants were required to have CELF-3UK CD and/or RS scaled scores below 5 and WISC-III PA and BD scaled scores above 6.

In order to increase numbers in the SLI group, four additional participants with SLI were recruited from outside the SNAP cohort, from special schools for children with language impairment known to clinical services at Guy's Hospital, London. It was not possible to complete the entire test battery of full WISC-III, CELF-3UK, ADOS-G and ADI-R for the additional participants. The ASD status of the adolescents with SLI was established using the ADOS-G and Social Communication Questionnaire (Rutter et al., 2003).

Seventeen typically-developing (TD) adolescents matched on chronological age with the clinical groups were recruited from a single school in South-West London. The school distributed letters and consent forms with pre-paid envelopes to the parents of all 14 year olds and participants were randomly selected from those who completed a consent form. The language and non-verbal learning abilities of the participants were screened to ensure language and nonverbal skills were in the average range using the CD and RS subtests from the CELF-3UK and PA and BD subtests from the WISC-III. The SCQ was used as an autism screening measure, with no participant obtaining a score greater than 6. Each participant was offered a small cash sum to recompense their time and effort. All families were added to the research mailing list to keep them informed of the findings of the study.

Table 1 shows the mean (SD) standardised scores the CELF-3UK and WISC-III subtests, together with ages and sex ratios. As expected, a series of univariate ANOVAs and post hoc Tukey HSD tests indicated that the language impairment participants had weaker language skills and similar nonverbal skills than the normal language group, confirming their language impairment status (all ps < .05). The TD group were significantly younger than the SLI group, but the three groups were matched on PA and BD scores. Both of the SLI and ALI groups showed lower CD and RS standard scores than the TD group. The participants with SLI and ALI also had lower BPVS scores than the TD participants.

---- Table 1 about here ----

Design

Participants' NWD performance was compared with traditional nonword repetition, using the Children's Test of Nonword Repetition (CNRep) (Gathercole & Baddeley, 1996). In the both the CNRep and NWD diagnostic status (SLI, ALI, TD) was treated as between-subjects independent variable. These groups allowed us to compare language impaired individuals with TD individuals and compare individuals with ALI with individuals with SLI. In NWD stimuli were created by manipulating two factors nonword length (short (2-syllables) or long (4-syllables)) and the position of the mismatching segment (word-initial or word-medial). These factors were crossed to create four conditions – Initial-Short, Initial-Long, Medial-Short, Medial-Long – providing the opportunity to investigate the independent contributions of PSTM and speech perceptual demands and their possible interaction in nonword processing. The Medial-Short condition was expected to be easy for participants regardless of language impairment. Following Donselaar (1996), participants were expected to show similar RTs to the TD participants on this condition and so it provided a check on whether the language impaired participants were able to manage the task demands. In CNRep the dependent variable was overall number correct (accuracy). In NWD both accuracy scores and reaction times to a speeded same/different judgement were recorded.

Materials

Children's Test of Nonword Repetition

The participants were administered the Children's Test of Nonword Repetition (CNRep) (Gathercole & Baddeley, 1996). The CNRep consists of 40 items ranging from two to five syllables in length, with ten items for each syllable length. The stress patterns of the words conform to the dominant stress patterns in English, and the nonwords are phonologically complex, with both branching onsets (e.g. consonant clusters) and branching nuclei (e.g. long vowels, diphthongs and codas). Some of the words contain syntactic morphemes (e.g. –ing), and derivational morphemes (e.g. –er, -ist) and many sound like English words.

Speeded Nonword Discrimination

NWD stimuli consisted of 40 nonword pairs which differed minimally and 40 nonword pairs which were the same. The latter acted as fillers items to ensure the probability of making a same or different response was the same. All nonwords, experimental stimuli and fillers, were generated using the same procedure. The CELEX database (Burnage, 1990) was used to determine the most common 2- and 4-syllable structures in English. These were

[CV][CVC], [CVV][CVC]. [CV][CV][CV][CV], and [CV][CV][CV][CVC] which accounted for 1.6%, 1.6%, .32% and .26% of the total word tokens for the spoken and written databases. A randomised procedure was used to generate nonwords. First, all of the words with a particular syllable structure were entered into a database. Then, within each syllable position, the syllables were randomly rearranged. From the list of randomly generated nonwords 20 of each syllable structure were selected for their word-likeness by two raters with a background in theoretical and clinical linguistics. Half of the nonwords (40) were chosen at random, and a mismatch version was generated.

In constructing the mismatching stimuli the aim was to provide a challenge to the speech perceptual system, whilst avoiding highly confusable contrasts. Single feature deviations were used as they are harder to detect than two or more feature deviations (e.g., Donsellaar, 1996). Deviations in place of articulation were used because they are more confusable than deviations in other phonetic dimensions and so should place more demands on the speech perception system, although the most confusable place contrasts, such as ϕ > T were avoided (Miller & Nicely, 1955). Taking account of these considerations a range of consonants were altered for the mismatching items. The same set of minimal contrasts were used to create mismatching nonwords in the four experimental conditions. When the mismatching segment occurred within a nonword it was chosen from the same set of phonemes used to create the word-initial mismatch items. This ensured the word-medial mismatch items were similar to the word-initial mismatch items. In each condition, six mismatches involved oral stop consonants (π > κ, β > δ, τ > π, τ > κ, δ > γ), two mismatches involved nasal stops (μ > ν), one mismatch involved fricatives (σ > Σ), and one mismatch involved approximants (ρ > φ). Eight dummy items were constructed in the same way to be used as warm-up items at the beginning of each half of the experiment.

The stimuli were all recorded in a soundproof booth by a female native speaker of Southern British English. Stimuli were recorded digitally to Minidisk at a sampling rate of 44.1 KHz. For the matched stimuli, two versions of the word were recorded to ensure that participants were not merely using echoic memory to match two identical wave forms. The recorded stimuli were imported onto a speech editing program (Audacity version 1.2.4) and split into individual sound files. The start and end point of each nonword was identified using the speech waveform. Spectrograms were used to set timing trigger points, which were placed at the beginning of the deviant segment for both the word-initial and word-medial items.

Procedure

NWD was implemented using the DMASTR/DMDX software (Forster, 2004). All of the stimuli were presented using a DELL laptop computer, and headphones (Pro-Luxe OA 850). A training session was conducted before the test itself, which allowed the participants to practise the paradigm. Three pairs of pictures were presented and then three word-pairs, played out from the PC. Pictures were used in order to introduce the paradigm. Participants pressed either the left Shift or the right Shift key to indicate if the pictures or words were the "same" or "different". Participants were asked which hand they used to write with, and the "same" key was allocated to their dominant hand. For example, left-handed participants pressed the left Shift button to indicate "same", and the right Shift button to indicate "different". During the training, the experimenter emphasised the need to respond as quickly and as carefully as possible, and continuously checked participants' understanding of which key corresponded to "same", and which key corresponded to "different". If the experimenter had any doubts about participants' understanding of the paradigm, the training was repeated.

Before commencing the NDW task participants were reminded to respond as quickly and as carefully as possible. Testing was initiated by pressing the space bar. Participants heard the first nonword in the pair, followed by a 200 millisecond (ms) pause, and then the second nonword in the pair. The experiment was self-paced, with the next pair of nonwords presented 500 ms after the participant responded by pressing the space bar. If the participant failed to respond they next pair stimuli was presented after 2 seconds and the response was treated as an error.

The test was divided into two halves of equal length (44 items), and each half began with 4 warm-up items. A short break was inserted in the middle, and participants could move on to the second part of the test when they were ready by pressing the Space bar. In order to control for any order effects, for example, loss of concentration towards the end of the testing session, the stimuli were presented in one of four orders. Each order was created by first randomising the stimuli, and then systematically swapping items to ensure that there were no runs of more than three same-pairs/different-pairs. Participants were assigned to these four orders as evenly as possible given that not all the groups were divisible by four.

Results

CNRep and NWD total scores

The mean (SD) totals of items correct for CNRep (maximum score = 40) for each diagnostic group are shown in Table 2. These data were compared using a univariate ANOVA with Group (TD, SLI, ALI) as a between-subjects factor. There was a significant effect of Group ($F(2,44) = 8.91$, $p = .001$, partial eta-squared = .288). Post hoc Tukey HSD tests revealed that the TD group were more accurate than the SLI and ALI groups ($p < .05$) but the SLI and ALI groups did not differ ($p > .05$).

---- Table 2 about here ----

The mean (SD) totals of items correct for NDW (maximum score = 40) for each diagnostic group are also shown in Table 2. A univariate ANOVA, with Group (TD, SLI, ALI) as a between-subjects factor, again showed a significant effect of Group ($F(2,44) =$

5.89, p = .005, partial eta-squared = .211). Post hoc Tukey HSD tests revealed that the TD group were more accurate than the SLI group ($p < .05$) but the TD and ALI groups did not differ and the SLI and ALI did not differ ($p > .05$) (see Table 2).

NWD accuracy scores

NWD scores are shown in Table 3. NWD scores were also analysed using a mixed ANOVA with Group (TD, SLI, ALI) as a between-subjects factor and Position (Initial, Medial) and Length (Short, Long) as within-subjects factors.

---- Table 3 about here ----

The main effect of Length was significant (F(1,44) = 13.74, p = .001, partial eta-squared = .238), participants were less accurate discriminating between long items (M = 8.4, SD = .2) than short ones (M = 9.0, SE = .2). But the position of the mismatch only marginally effected accuracy (F(1,44) = 3.02, p = .089, partial eta-squared = .064). Decisions to initial mismatches (M = 8.6, SE = .2) were less accurate than those to medial ones (M = 8.9, SE = .2). The interaction between Position and Length in the decision latencies was not found in the accuracy scores ($p > .1$). The interaction between Length and Group was marginally significant (F(2,44) = 2.92, p = .064, partial eta-squared = .117). The other two-way and three-way interactions between Group and Position and Length were not significant ($p > .1$). The marginal interaction between Group and Length was further investigated by analysing simple effects. Both of language impaired groups were less accurate to long items than short ones. In the SLI group the estimated marginal mean for short items = 8.4 (.3) and for long items = 7.7 (.4) (F(1,44) = 5.50, p = .024) and in the ALI group the estimated marginal mean for short items = 9.0 (SE = .3) and for long items = 8.1 (.4) (F(1,44) = 13.37, p = .001). The TD group did not show this effect (Short = 9.5 (.3), Long = 9.4 (.4); $p > .1$).

NWD Reaction times

Responses for the mismatching items (i.e., the experimental conditions) were used in the analyses. Reaction times (RT) less than 200 ms (4 responses) were treated as pre-emptive responses and excluded from the data. The RTs over the 2000 ms time-out (26 responses) were automatically coded as errors along with the "Same" responses to the mismatching items. All other correct responses to mismatching items were included untransformed in the analyses of RT data (see Table 4).

---- Table 4 about here ----

A mixed ANOVA with Group (TD, SLI, ALI) as a between-subjects factor and Position (Initial, Medial) and Length (Short, Long) as within-subjects factors was used to model the RT data. There was a significant main effect of Position ($F(1,44) = 46.02$, $p < .001$, partial eta-squared = .511), RTs were slower to word-initial mismatches (M = 862.7 ms, SE = 20.3) than word-medial ones (788.0 ms, SE = 16.9), and Length ($F(1,44) = 102.20$, $p < .001$, partial eta-squared = .699), RTs were slower to long nonwords (872.8 ms, SE = 17.9) than short ones (777.8 ms, SE = 18.9). There was also a significant interaction between Position and Length ($F(1,44) = 20.23$, $p < .001$, partial eta-squared = .315). But there were no two-way and three-way interactions between Group and the stimulus variables Position and Length (all ps > .1). Hence, the groups responded in a similar way to manipulations of mismatch position and stimulus length, suggesting no evidence for a disproportionate effect of increasing either speech perception or PSTM load on the participants with language impairment.

The interaction between Position and Length (shown in Figure 1) was further investigated by analysing simple effects. Initial mismatches generated significantly longer RTs than medial mismatches for both short items (estimated marginal mean for Initial = 797.2 (SE = 22.2), Medial = 762.0 (17.2); $F(1,46) = 1701.95$, $p < .001$) and long items (Initial = 932.9 (19.0), Medial = 815.6 (17.0); $F(1,46) = 2379.19$, $p < .001$).

---- Figure 1 about here ----

A significant main effect of Group was found ($F(2, 44) = 3.69$, $p = .033$, partial eta-squared = .144). Post hoc Tukey HSD tests indicated that the ALI group had slower overall reaction times (M = 877.0; SD = 106.1) than the TD group (M = 768.8; SD = 108.3), other comparisons were not significant (SLI: M = 835.0; SD = 133.1). A univariate ANOVA with group (TD, SLI, ALI) as a between-subjects factor carried out on the RTs for the Short-Medial condition, which was predicted to be the easiest for all participants, showed a marginal effect of Group ($F(2, 44) = 2.95$, $p = .063$, partial eta-squared = .118). However, post hoc Tukey HSD tests revealed no between group differences ($p > .05$). This suggests that all participants were equally able to meet the task demands.

Discussion

This study aimed to investigate possible cognitive bases of impaired nonword repetition in SLI and ASD. A novel task, NWD, which manipulated PSTM and speech perception load in a way not possible in nonword repetition, allowed us to investigate the contribution of these factors to nonword processing. We found evidence for both factors influencing decision latencies in individuals with and without language impairment. RTs suggested that adolescents with SLI and ALI were affected by increasing PSTM and speech perception loads in a similar way to TD adolescents. Participants' judgements were slower to 4-syllable compared to 2-syllable nonword pairs and slower to nonword pairs that mismatched on word-initial phonemes as compared to word-medial phonemes. These factors interacted, with 4-syllable, word-initial mismatch pairs leading to slowest decision latencies. However, there was some evidence, albeit weaker, that individuals with language impairment may have been less accurate with long nonword pairs than TD individuals, suggesting they may be disproportionately affected by the PSTM load.

Unravelling the roles of PSTM and speech perception in nonword processing

NWD required the listener to hold stimuli in PSTM in order to compare them. This was more difficult when the items were long, suggesting nonword discrimination is sensitive to PSTM load. This finding replicates a wealth of evidence that PSTM plays an important role in typical and disordered language processing (for a review see Montgomery, 2003). The position of the deviant segment in mismatching nonword pairs was varied in order to manipulate the speech perception load. All the stimuli were nonwords and so listeners could not rely on lexical knowledge to identify mismatches. However, the ability to use bottom-up information in the form of acoustic-phonetic cues to identify upcoming segments may explain the mismatch position effect. Marslen-Wilson and Warren (1994) found that listeners' real-time lexical access was disrupted by a mismatch between vowel transition and release-burst information in a following consonant, demonstrating listeners' use of fine-grained acoustic-phonetic information in spoken word recognition. Listeners may apply this processing capacity in NWD. When a mismatching segment is word-medial, listeners can compare the current acoustic-phonetic input against their representation of the first nonword, using the information in the vowel preceding the deviant segment to start making a decision, before the segment is encountered. This is not possible for word-initial mismatches, where is no preceding acoustic-phonetic material. Furthermore, the interaction found suggests that speech perception load and PSTM are influencing each other. This integration of PSTM and speech perception in language processing is consistent with the model proposed by Jacquemot and Scott (2006) which sees PSTM as a property that emerges from the cycling of information between phonological input and output buffers, the former serving speech perception and the later speech production.

PSTM and speech perception in SLI and ALI

NWD was able to provide evidence for PSTM and speech perception interacting during speech processing in a similar way in individuals with and without language impairment. We found no evidence in NWD RTs of a disproportionate effect of increasing speech perception or PSTM loads on the SLI and ALI groups. This suggests that at some level the processing substrate that supports PSTM and speech perception is intact in adolescents with SLI and ALI . It is possible to argue that in the case of speech perception this is not surprising as the evidence for speech perceptual problems being associated with language impairment is equivocal. Much evidence suggests language impairment is not associated with speech perception deficits. Children with SLI are able to recognise spoken words with the same amount of speech input as children without SLI (Montgomery 1999), and show unimpaired discrimination for synthetic CV strings (Burlingame et al., 2005) and brief nonspeech stimuli (Bishop et al., 2005). The lack of a PSTM effect in the RTs is more unexpected because of the well-established association between language impairment and deficits in tasks measuring PSTM. However, there was some evidence of length effects in the NWD accuracy scores. The SLI and ALI groups, but not the TD group, made more errors to long as compared to short stimuli, leading to a marginal interaction between group and stimulus length but significant simple effects. The weakness of the interaction may have been due to low power in the study resulting from the relatively small sample size and the variability especially in the language impaired groups. Although the effect sizes for the RT results are medium to large, those for the accuracy scores are small to medium. The close to ceiling accuracy for all groups may also have contributed to the weakness of the effect. Assuming that the length effect in the accuracy scores between the language impaired and TD groups represent real difference, the contrasting pattern of results found in RTs and accuracy scores needs to be explained. RTs reflect processing when participants make correct responses. In this case, the decision latencies of adolescents with language impairment are influenced by PSTM and speech perception loads in a similar way to TD adolescents. But individuals with language impairment are less accurate. When they make errors, they are influenced by item length (i.e., by PSTM load) not by mismatch position (i.e., by speech perception load). This suggests speech perception is not impaired in individuals with language impairment, by the time they reach adolescence, whereas PSTM may be. These findings for the SLI and ALI in NWD appear to be consistent with the results from nonword repetition, where both language impaired groups had lower scores than the TD group and which is taken as evidence for deficits in PSTM. We find little evidence in NWD for underlying differences in nonword processing in SLI and ASD that Bishop et al. (2004) suggested might be the case for nonword repetition. Speech perception deficits may have been evident in younger individuals and so the age of the participants may be considered a limitation of the current study. This may also be seen as an appeal of the study because it allowed us to capture language processing abilities in SLI and ALI at the end of development. However, investigation of NDW performance in younger children would be a future direction for research.

NWD also provided an opportunity to investigate different components of nonword processing. Archibald and Gathercole (2007), comparing serial recall and nonword repetition in ten-year olds with SLI, found nonword repetition deficits persisted even when PSTM load was factored out. They argue that poor nonword repetition performance in SLI is not solely the result of a PSTM deficit and suggest that one or a combination of phonological processing, auditory perception and speech-motor output demands may play a role. NWD may allow the speech-motor demands to be discounted as an explanation. It was designed to probe the effects of speech perception load and so this may also be discounted. However, it is possible that individuals with language impairments may have problems with some aspects of phonological and/or auditory processing not tapped by the way speech perception load was manipulated in NWD. Alternatively other factors such as auditory attention may play a role in the deficits found. Thus, Montgomery (2008) reported that real-time comprehension of simple sentences was associated with indices of auditory attention in 8-year olds with SLI but not age matched controls and children with ASD also show significant deficits in auditory attention (Corbett & Constantine, 2006). These are issues for further investigation which may be addressed by developing the approach introduced here.

Conclusions

This study investigated the cognitive bases of impaired nonword repetition in SLI and ASD using a novel task, NWD, which manipulated PSTM and speech perception load. Results suggest that there are similarities and differences between adolescents with SLI and ALI and their TD peers. The reaction time data provide evidence for PSTM and speech perception interacting during speech processing and indicated that adolescents with language impairment were affected by increasing PSTM and speech perception loads in a similar way to typically developing adolescents. However, adolescents with language impairment were less accurate than TD individuals, with both the SLI and ALI groups showing a clear effect of PSTM load. Adolescents with SLI and ALI showed an similar pattern of performance which may indicate, at some level, the processing substrate supporting both PSTM and speech perception is intact, but also there is impaired access to PSTM resources.

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Table 1. Age, language and nonverbal abilities of participants (Mean (SD))

	TD (N= 17, 7 females)	SLI (N= 14, 1 female)	ALI (N= 16, 0 females)	ANOVA	Group differences (p < .05)
Age	172.7 (4.2)	180.5 (4.9)	176.3 (5.8)	F(2, 44) = 13.28, p < .001	SLI > TD; SLI = ALI; TD =ALI
CD	10.1 (2.6)	4.2 (0.8)	4.5 (1.4)	F(2, 44) = 44.32, p < .001	TD > SLI = ALI
RS	9.1 (1.9)	3.8 (1.3)	4.9 (1.6)	F(2, 44) = 52.30, p < .001	TD > SLI = ALI
BPVS	106.4 (20.0)	84.5 (7.5)	80.4 (9.0)	F(2, 44) = 15.82, p < .001	TD > SLI = ALI
PA	12.7 (3.9)	13.6 (3.0)	12.6 (4.0)	F(2, 44) = .32, p > .1	TD = SLI = ALI
BD	9.6 (2.9)	10.1 (3.4)	10.6 (3.3)	F(2, 44) = .38, p > .1	TD = SLI = ALI

Table 2. Mean (SD) total scores for Children's Test of Nonword Repetition (CNRep) (max = 40) and nonword discrimination (NWD) (max = 40).

	TD	SLI	ALI	Group differences (p < .05)
CNRep	33.4 (3.4)	25.9 (7.0)	28.9 (4.3)	TD>SLI=ALI
NWD	37.8 (1.7)	32.1 (6.3)	34.1 (5.2)	TD>SLI; TD=ALI; SLI=ALI

Table 3. Mean (SD) correct responses by condition for nonword discrimination

	TD	SLI	ALI	Group differences ($p < .05$)
Initial-Short	9.2 (1.3)	8.6 (1.6)	9.1 (.9)	TD=SLI=ALI
Initial-Long	9.2 (1.0)	7.6 (1.8)	7.7 (2.2)	TD>SLI=ALI
Medial-Short	9.8 (.4)	8.1 (1.9)	8.9 (1.6)	TD>SLI; TD=ALI; SLI=ALI
Medial-Long	9.6 (.6)	7.8 (2.2)	8.4 (1.4)	TD>SLI; TD=ALI; SLI=ALI

Table 4: Mean (SD) reaction times in milliseconds for nonword discrimination.

	TD	SLI	ALI
Initial-Short	734.4 (117.0)	815.1 (211.1)	842.0 (120.3)
Initial-Long	857.1 (117.1)	954.1 (136.1)	987.5 (136.2)
Medial-Short	710.2 (126.4)	766.6 (121.0)	809.3 (103.7)
Medial-Long	773.3 (115.8)	804.4 (130.5)	869.1 (103.4)

Figure 1. Nonword discrimination mean reaction times in milliseconds (with standard error bars) for data combined across all groups.