MODALITY EFFECTS AND ECHOIC MEMORY

A Comparison of Modality Effect Performance in Children: How Reading Achievement Performance is influenced by Echoic Memory

by

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ABSTRACT

This study investigates if less skilled readers suffer from deficits in echoic memory, which may be responsible for limiting the progress of reading acquisition. Serial recall performance in auditory, visual, and noisy conditions was used to assess echoic memory differences between skilled and less skilled readers. Both groups showed the typical modality effect, demonstrating that each had a functioning echoic memory. Less skilled readers performed more weakly than skilled readers on noisy serial recall, suggesting that the recall of less skilled readers is more vulnerable to interference than the recall of skilled readers. Nonword repetition performance indicated that all participants had reduced recall as a function of word complexity and word length. No difference between reading groups was found on this task; however, as nonword repetition and size of modality effect did not correlate, this task may not be a measure of echoic memory.

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Research has demonstrated that the modality of presentation can influence the effectiveness of short-term memory (see Penney, 1989, for a review). The modality effect in immediate recall refers to the superiority of recall for auditory (spoken) presentation over visual (print) presentation of items. In serial recall, this effect is found only for the recency portion of a list-- the most recent two to three items. The modality effect decreases when auditorily presented distracting verbal material is included between list presentation and recall. The purpose of this study is to determine if there is any relationship between short-term memory performance and reading achievement, by studying the modality effect. The modality effect among skilled readers appears to be quite strong, but this effect may differ in less skilled readers due to a weaker echoic memory.

The most thoroughly studied example of a modality specific interference effect is the suffix effect. The suffix effect refers to a selective reduction in the recency portion of the serial position curve. This occurs when a serial recall list is followed by the inclusion of an additional item, such as the word “go”, which does not have to be recalled. The key result is that an auditory suffix decreases the recall of auditory items more than a visual suffix. A visual suffix usually has no effect on the recall of auditorily presented words. Both the number of serial positions showing the modality effect, and the length of time over which the modality effect and suffix effect occur, seem to be parallel (Penney, 1989). The suffix appears to act as an additional memory item, interfering with the recall of the most recent memory items.

Modality and suffix effects appear to reflect the same underlying mechanism, an echoic store that is specific to the auditory modality. Evidence for this echoic store has been provided by the presence of the modality effect in digit-span tasks. Auditory items appear to last for a longer period of time than visual items (Watkins & Watkins, 1980). The duration of modality effects suggests that echoic information may last in silence for up to 60 seconds (Engle & Roberts, 1982). The sensory information that underlies both the modality effect and suffix effect appears to provide valuable information which contributes to the recall of auditory, but not visual information. The sensory trace lasts long enough to be useful for recall of the two or more most recently presented items in immediate serial recall tasks. The research of Watkins and Watkins (1980) and Engle and Roberts (1982) suggests that echoic information can last a long time in the absence of auditory distracters. This echoic information underlies both the modality and the suffix effect, supporting the recall of auditory stimuli, but not visual stimuli.

Studies on modality effects in immediate and delayed free recall in children were carried out by Murray and Roberts (1968) and Dempster and Rohwer (1983). These investigators determined that the modality effect in the recall of normally developing children is robust. Retention in both immediate and delayed free recall tasks appears to be better with auditory presentation than visual presentation. Murray and Roberts (1968) determined that auditory presentation results in stronger recall than does visual presentation, and this modality effect is found at all presentation rates, but is largest at the faster rates. These studies also illustrate that as children age, the amount of information that can be stored in short-term memory and the speed of processing appear to improve (Dempster & Rohwer, 1983; Murray & Roberts, 1968).

The modality effect in skilled readers appears to be quite strong, but the performance of less skilled readers may be poorer due to a weaker echoic memory. Less skilled readers tend to display larger suffix effects than those seen in skilled readers (Gillam, Cowan, & Day, 1995; Sipe & Engle, 1986). Larger suffix effects indicate that the echoic memory of less skilled readers may be more susceptible to interference than that of skilled readers. Less skilled readers also have greater difficulty than skilled readers and they are more prone to phonetic errors when perceiving words in noise-masked conditions (Brady, Shankweiler, & Mann, 1983). The presence of phonetic errors and difficulties in the perception of speech suggests that less skilled readers have greater difficulty forming complete phonological representations. Dyslexic children are more impacted than non-dyslexic children by noise, and they show more difficulty perceiving the differences in phonemes when noise is present (Ziegler, Pech-Georgel, George, Alario, & Lorenzi 2005; Ziegler, Pech-Georgel, George, & Lorenzi, 2009). Noise increases the difficulty of encoding phonological representations and leads to phonological representations that are less stable in dyslexics than in other comparison groups such as reading groups matched for reading age and chronological age (Ziegler et al., 2009).

Imprecise phonological representations can contribute to difficulties in naming tasks, leading to difficulties in creating, retrieving, and using phonological representations (Fowler & Swainson, 2004). Less skilled readers perform worse on nonword repetition tasks than skilled readers, which suggests potential deficits in phonological memory processes (Gathercole, Willis, Baddeley, & Emslie, 1994). Children suffering from severe language impairments process information more slowly and have greater difficulty holding verbal items in memory, which may lead to impairments in processing and acquiring language (Archibald & Gathercole, 2006). Therefore, there is some evidence to suggest that the echoic memory of less skilled readers does not last as long, has a smaller capacity or is more subject to interference than the echoic memory of skilled readers.

Research by Penney and Godsell (1999) suggests that echoic information does not persist as well in less skilled readers as it does in skilled readers. Skilled and less skilled readers were classified by means of a median split on the raw scores of the Word Attack subtest for the Woodcock-Johnson battery. For skilled readers, recall of auditory lists was slightly higher than recall of visual lists; for less skilled readers, the reverse occurred and recall for visual lists was higher. Penney and Godsell's (1999) finding of an interaction between reading ability and presentation modality has not been replicated. Tobin (1999) was not able to replicate their interaction, and it is important to determine whether the reason for this failure to replicate is due to Penney and Godsell's (1999) use of slightly noisy stimuli. Their research suggests that less skilled readers do have an echoic representation of the items heard, but the representation is more vulnerable to decay and interference. However, further research is required to fully understand the relationship between reading achievement and short-term memory performance.

The purpose of the present research is to study the modality effect and to determine whether less skilled readers suffer from a deficit in echoic memory that may contribute to their low level of reading achievement. The central hypothesis of this study is that less skilled readers have less efficient echoic memory or echoic memory with less capacity and greater susceptibility to interference than skilled readers. For the purposes of this study, less skilled readers are defined as children who are not performing at a commensurate level with their peers as measured by the Word Identification subtest of the Woodcock Reading Mastery Test (WRMT; Woodcock, 1987). This will be investigated by examining the relationship between reading achievement and short-term memory performance.

Serial recall and nonword repetition are the two short-term memory tasks that will be used to measure echoic memory. If the echoic memory of less skilled readers is impaired, this should be reflected in a smaller modality effect due to less benefit from auditory presentation. It is also expected that the memory of less skilled readers will be more vulnerable to interference; this should be especially evident when participants are tested with a serial recall condition including noise. If the echoic memory of less skilled readers is more vulnerable to decay than the echoic memory of skilled readers, performance on nonword repetition tasks and serial recall should show reduced accuracy when compared.

Early models of echoic memory

The original interpretation of the modality and suffix effects was that there was a short-term auditory sensory store known as echoic memory or the precategorical acoustic store (PAS), which maintained a representation of several words or numbers for several seconds— just long enough to be useful in immediate recall tasks. The modality effect is due to the persistence of auditory information in the PAS which facilitates recall of the last few auditory items. The suffix effect arises because auditory information in the PAS can be displaced by subsequent verbal items. Crowder and Morton (1969) proposed that material in the PAS was subject to overwriting and to decay with time. According to Crowder and Morton, once the sensory trace was displaced or access to the trace was disrupted, there was no difference in short-term or long-term memory traces of items originally presented auditorily or visually.

The PAS model explained why there was no modality effect in early list items, and was able to account for the interfering effects of the stimulus suffix. Crowder and Morton's (1969) theory of auditory short-term memory dominated the literature for more than a decade.

Separate streams theory

Penney (1989) summarized five lines of evidence that are inconsistent with the PAS model. The work of Watkins and Watkins (1980), and Engle and Roberts (1982), found that modality and suffix effects are apparent after delays as long as 30 seconds, and extend over more than one to two items. The second finding is the observation of both auditory and visual selective interference effects. Retention decreases when the same modality is involved in processing the memory and interference tasks. The third finding consists of evidence of improved memory when different items are presented to two modalities. Mixed-mode presentation can result in a greater capacity for recall, relative to single-mode presentation (Broadbent, 1956; Frick, 1984). Short-term retention can be improved with presentation of items to two sensory modes, making available additional processing capacity relative to single-mode presentation. The second and third findings show that there are separate pools of processing resources for auditory and visual modalities. The fourth finding is that presentation modality appears to be a powerful dimension for organization in memory. Organization by modality is not a strategy that can be abandoned at will; instead it is an inherent part of the structure of the memory system (Penney, 1980; Rönnberg, Nilsson, & Ohlsson, 1982). The fifth finding consists of neurological evidence of short-term memory deficits that are specific to the auditory and visual modalities.

To account for the many findings that were inconsistent with the PAS model proposed by Crowder and Morton (1969) and subsequent revisions (1978, 1983), Penney (1989) proposed the separate streams model of short-term memory. The fundamental difference between the PAS model and separate-streams theory is that in Penney's (1989) theory, visual and auditory inputs are processed separately in short-term memory, with each processing stream drawing from a separate pool of resources. According to the PAS model, once information has been lost from the PAS, immediate recall takes place from the verbal short-term store in which the medium of retention is subvocal rehearsal. Presentation modality contributes little more than a tag indicating what the modality was. In contrast, Penney argues that there are two separate processing streams for auditory and visual information.

Penney (1989) argued that the short-term memory trace created when one silently articulates a visual item is different from the memory trace created when one hears the items presented auditorily. The code generated by silent articulation of the visual item is called the phonological code (or P code) and the sensory-based code that is created as a result of auditory presentation is the acoustic code (or A code). In the auditory stream, items are represented automatically in both A and P codes. The capacity of the A code appears to be five items or more, and research shows that this code can last up to 60 seconds under ideal conditions (Engle & Roberts, 1982; Watkins et al., 1980).

For items (words or images) presented in the visual modality, P-code representations are normally generated for rehearsal. However, generation of the P code is not automatic and can be disrupted by simultaneous speech (Penney, 1989). The P code has a relatively weaker temporal component than the A code. For auditory presentation, successive items in the A code are strongly associated, but simultaneously presented items are not; in contrast, simultaneously presented items in the visual modality are more strongly associated than the successive items. When different items are presented in different modalities simultaneously or sequentially, both processing streams are used and the participant is therefore able to make use of both pools of resources. As long as items are available in the A code, recall of mixed mode lists will be higher than recall from lists presented in one modality. Information in the A code, according to Penney, does not decay but is highly susceptible to interference from subsequent auditory input.

Modality Effects and Language Disorders

Studies of auditory memory in children with language impairment have found that these children tend to recall significantly less than their chronological age-matched peers and also show differences in terms of their susceptibility to the suffix effect. Research on the suffix effect has suggested that the recall of children with language impairment may be more vulnerable to decay and interference relative to typically developing children (Sipe & Engle, 1986; Gillam, Cowan, & Day, 1995). These impairments have the potential to slow processing time, contributing to limitations that may affect processing time, speech perception, and the quality of phonological representations. Gillam, Cowan, and Day (1995) used a suffix effect procedure to compare the performance of language-impaired children with the performance of chronological age-matched and reading age-matched children. A spoken list of digits was followed by a suffix that was not to be recalled. Digit span lists varied from four to nine digits in length. As expected, the suffix had a detrimental effect on the recall of items from the end of the list. This effect was larger in language-impaired children than in chronological age-matched and reading-age matched children. The larger suffix effect indicates that the children's echoic memories were more susceptible to interference than echoic memory in the normally developing children.

To investigate differences in echoic memory between skilled and less skilled readers, Sipe and Engle (1986) conducted two experiments using a suffix procedure. The first experiment assessed differences in the suffix effect using digit lists that were one item larger than the participants' respective memory spans. The span-plus-one item condition was used to equate task difficulty for all participants. The within-subjects variables were suffix condition (speech suffix or tone control), list length (the child's measured digit span, or span-plus-one item) and rate of presentation (one or four digits per second). Because list length was matched to the subject's digit span, less skilled readers and skilled readers showed equal performance over recency positions in the non-suffix conditions. Recall performance was examined for the first four and last four serial positions in each list. Both groups showed a primacy effect and there was no difference in the extent of primacy between skilled and less skilled readers. To the extent that rehearsal is involved in primacy effects, this suggests that skilled and less skilled readers do not differ in terms of rehearsal.

Less skilled readers showed a larger suffix effect on the terminal item than skilled readers. This effect was replicated in Experiment 2, using the span-plus-one condition and a faster rate of presentation (four digits per second). Sipe and Engle (1986) found a significantly larger suffix effect in the performance of less skilled readers than in skilled readers. The larger suffix effect found in both experiments indicates that skilled and less skilled readers differ in the structure and function of echoic memory.

Sipe and Engle (1986) used a dichotic listening task in their third experiment to measure the duration of echoic memory. The participants were presented with two simultaneous auditory messages, one to each ear, and were asked to shadow one of the messages. One track contained the letters to be shadowed, and the second track contained the message to be ignored, which included both letters and digits. After a short period of time following presentation of the target digit, a visual signal occurred, and the subject was then asked to stop shadowing and recall the digit most recently presented to the non-shadowed ear. The length of the delay of the recall varied from no delay to 16 seconds. Sipe and Engle (1986) assumed that the non-shadowed message was stored in echoic memory and that the subject was not attending to the distractor message. If the message had not received attention, it would not be rehearsed. Varying the delay between presentation of the digit and the recall cue was expected to reveal how retention in echoic memory declined as the amount of interfering information increases. The difference between skilled and less skilled readers, in terms of the duration of echoic memory, should be reflected in diminishing recall performance of the digits as cue delay increases.

Skilled and less skilled readers performed equally well on the digit recall task when testing occurred immediately after presentation, but as the retention interval increased, the performance of less skilled readers declined faster than the performance of skilled readers. After a delay of 8 seconds, the performance of less skilled readers reached chance level, while skilled readers did not reach asymptote even after a 16-second delay. These findings support the hypothesis that less skilled readers suffer a more rapid loss of information from echoic memory than do skilled readers.

The work of Sipe and Engle (1986) shows that less skilled readers demonstrate a larger suffix effect than skilled readers, and their recall also shows a faster decrement over time. The larger suffix effect implies that the echoic memory of less skilled readers is more vulnerable to interference than that of skilled readers. The faster drop in recall over time suggests that the echoic memory of less skilled readers has a faster rate of decay. Sipe and Engle (1986) argued that less skilled readers might suffer from echoic memory deficits; the larger effect of the suffix may result from an echoic memory trace that is more vulnerable to interference, has a smaller capacity, or faster rate of decay than the echoic memory of skilled readers. Sipe and Engle's research supports the possibility that the echoic memory of skilled and less skilled readers differs in a meaningful way. If the echoic memory trace decays faster and is more vulnerable to interference for less skilled readers than for skilled readers, greater repetition of a word will be needed in order to establish an adequate phonological representation. A child that suffers from a weak echoic memory will require more repetition and exposure to words in order to develop the letter-to-sound associations that are required for reading. An inefficient echoic memory may result in slower processing and impoverished phonological representations, in turn delaying reading achievement progress for less skilled readers.

Penney and Godsell (1999) compared modality effects in skilled and less skilled readers who were recruited from a population of university students. Participants were classified as skilled or less skilled readers on the basis of a pseudoword reading task from the Woodcock-Johnson battery. The students were tested on an immediate serial recall task of auditory and visual digits. Skilled readers demonstrated a typical modality effect, with higher recall of auditory than visual items from the last three serial positions. Less skilled readers showed a typical modality effect on the last item, but, in contrast to skilled readers, there was a reverse modality effect on items prior to the final item; that is, visual presentation produced higher recall. The presence of the typical modality effect on the terminal item indicates that less skilled readers did have a functioning echoic memory and were capable of using information from the auditory memory store when retrieving the terminal item. Consistent with the work of Sipe and Engle (1986), Penney and Godsell's findings suggest that echoic information does not persist as well in less skilled readers as it does in skilled readers. Less skilled readers do have an echoic representation of the items heard, but the representation is more vulnerable to decay and interference.

Tobin (2000) attempted to replicate Penney and Godsell's (1999) findings by testing skilled and less skilled readers recruited from a high school. While Penney and Godsell found that less skilled readers exhibited a smaller modality effect than skilled readers, Tobin found no interaction between modality and reading skill, and did not replicate Penney and Godsell's findings. One possible reason for this inconsistency is that Tobin used high quality tape recordings, while Penney and Godsell used early technology for computer presentation of speech, and the stimuli were slightly noisy. Noise has the potential to influence memory performance, and it is possible that the addition of noise may have impacted the findings.

Noise can have a powerful effect on memory, even when speech identification errors do not occur. A common assumption is that when a speech sound is accurately identified, the noise does not influence memory performance. This may not the case. In two experiments, Surprenant (1999) investigated the effect of noise on memory for spoken syllables. Thirty participants were tested on an immediate serial recall task of six consonant-vowel syllables in three different noise conditions: a quiet condition, or with added noise (+10 or +5 Db speech-to-noise ratio, respectively). Two experiments showed that although identification of syllables was at the same level for all noise conditions, the addition of noise reduced overall recall and recency performance. Surprenant argued that if listeners rely primarily on modality-independent features, there should be no effect of noise on early serial positions. However, there were substantial effects of noise at the beginning of the serial position curve, indicating that the addition of noise acts as a secondary task. Significant interactions between noise and serial position showed that the addition of white noise (+10 Db speech-to-noise ratio) reduced performance at every serial position, and the addition of broad-band noise (+5 Db speech-to-noise ratio) further reduced performance, but only for the last two serial positions. Adding noise increases the amount of resources required to process the task, impairing memory performance.

Surprenant's findings offer an explanation for Tobin's (2000) inability to replicate Penney and Godsell's (1999) findings. Noise can act as a secondary task; it limits the efficiency of the encoding of information and can result in measurable decrements in overall recall. The addition of noise degrades the echoic memory trace, rendering it less useful. This may lead to a decrease in echoic memory performance. The stimuli used by Penney and Godsell (1999) were slightly noisy, and this might explain why Tobin was unable to replicate their findings of a smaller modality effect for less skilled readers as well as the interaction between modality and reading skill. Therefore, it is important to replicate Penney and Godsell's study using clear auditory presentation, presentation with noise, and visual presentation.

The purpose of the current research project is to explore the effects of noise on serial recall in skilled and less skilled readers. If less skilled readers exhibit a larger decrement in performance in the presence of noise than do skilled readers, this would confirm that their echoic memory has greater vulnerability to interference. Serial recall performance is expected to be most accurate with auditory presentation, followed by noisy presentation and visual presentation. Differences in serial recall performance between skilled and less skilled readers will help clarify differences in the structure and function of echoic memory.

Effect of Noise on Dyslexics

Ziegler, Pech-Georgel, George, Alario, and Lorenzi (2005) have shown that children with language learning disabilities exhibit poor speech perception in noise for fast, as well as slow amplitude-modulated noise conditions. Ziegler, Pech-Georgel, George, and Lorenzi (2009) replicated their earlier work on speech perception in noise to determine whether in comparison to reading-level controls, dyslexics would exhibit greater speech perception deficits in noise than in silence. The investigators explored whether dyslexics show a normal noise-masking effect and whether they exhibit the same pattern of phonetic deficits as the language-impaired children in their previous study (Ziegler et al., 2005). They also aimed to determine whether noise is a necessary or sufficient condition for repetition errors to occur when participants orally identify vowel-consonant-vowel stimuli, and whether speech perception in noise predicts reading performance beyond general cognitive ability. They hypothesized that decreased performance should be observed in speech perception for all speech conditions degraded by noise.

In Ziegler et al.'s (2009) study, 19 dyslexic children were tested and compared to two groups of controls: one group was matched on chronological age and the other on reading age. In order to determine whether speech perception in noise explained unique variance in reading, children were tested on a series of tasks to assess the contribution of general cognitive ability, verbal memory, visual and auditory processes, and sustained attention. For the speech perception in noise task, children were presented with vowel-consonant-vowel utterances and were asked to repeat each stimulus. The results showed that dyslexic children had a speech perception deficit in noise and no speech perception deficit in silence, and this interaction was significant when dyslexics were compared with reading age-matched controls.

When dyslexics were compared with chronological age-matched controls, there was a significant masking release effect for each noise condition. Masking occurs when a more intense sound makes a less intense sound more difficult to hear. In normal background noise, speech recognition relies on the integration of masked spectral and temporal speech cues. A normal masking release effect is defined by Ziegler et al. (2005) as showing better performance in fluctuating noise than in stationary noise when perceiving speech cues. The presence of a normal masking release effect suggests that the sensory and cognitive processes that are involved in masking release (such as auditory grouping based on stimulus spectral and fine-structure cues, perceptual restoration and informational masking), are functional in children with severe language impairment. Masking release effects show that the auditory system is capable of taking advantage of the fluctuating background to detect speech cues. Ziegler argues that if dyslexics show a normal masking release, this suggests that low level auditory processes are intact, and that any perception deficit in noise is not rooted in poor temporal or spectral resolution but instead suggests the presence of phonetic deficits. When dyslexics were compared with chronological age-matched controls and with reading-age matched controls, there was a significant masking release effect for each noise condition. No significant interaction occurred between masking release and group in any of the noise conditions, confirming that dyslexics demonstrate a normal masking release effect with respect to both control groups. The normal masking release effect exhibited by dyslexics suggests that in the presence of noise, phonetic deficits may contribute to a lack of speech robustness. The speech perception in noise task explained a significant amount of unique variance in reading after accounting for potentially confounding factors of general cognitive ability, auditory perception, sustained attention, verbal production, or verbal memory. Based on these results, the researchers concluded that speech perception in noise predicts reading skills beyond the contributions of the previously mentioned factors.

Ziegler et al. (2009) suggest that the speech perception deficits exhibited by dyslexics most likely arise in the mapping of acoustic features onto phonological categories. The complexity of the encoding process is made more difficult in the presence of noise. When noise distorts speech cues, the process of integrating acoustic features into phonological categories is disrupted. Dyslexics showed strong deficits in phonology, especially in phonological awareness and word repetition. Dyslexics showed greater difficulty than control groups when reading regular and irregular words, as well as nonwords. Ziegler et al. (2009) suggest that the addition of noise results in poor access to phonological representations and a lack of speech robustness. A lack of speech robustness means that the phonological representations of dyslexics are less stable than those of children with typical language development.

Ziegler et al. (2009) argued that learning to read is primarily based upon mapping orthography onto phonology. Children learn grapheme-phoneme correspondences and this knowledge helps to promote phonemic awareness. Deficits existing in the process of auditory processing can create problems in the perception of speech, thereby slowing the mapping process. If difficulties exist in mapping sound to letters, a struggle to decode words efficiently is likely to follow. In the presence of noise, the learning of grapheme-phoneme correspondences becomes much more difficult for dyslexics. If noise affects dyslexic children more than non-dyslexic children, the dyslexic children may have greater difficulty in perceiving the differences between certain phonemes when noise is present. Ziegler et al. (2009) argued that in order for listeners to recover from noise, the successful integration of a number of different speech cues is required. For dyslexics, the ability to simultaneously integrate speech cues necessary for speech identification is deficient. This leads to poor access to phonological representations, delays in the development of an orthographic lexicon, and for potential delays in the progress of reading acquisition.

Brady, Shankweiler, and Mann (1983, Experiment 1) investigated whether the memory deficit exhibited by less skilled readers may have its origin in perception, reflecting a less efficient use of phonetic code. Their research (Brady et al., 1983, Experiments 2 and 3) was also the first to test the ability of skilled and less skilled readers to repeat words that were degraded by noise. The skilled readers were 15 third-grade students with a mean reading level of 5.88, which is above third-grade reading skills. The less skilled readers comprised 15 students with a mean reading level of 2.76, slightly more than half a year below their grade level. Vocabulary skills were measured using the Word Recognition and Word Attack subtests of the Woodcock Reading Mastery Test. The stimuli consisted of 20 strings of five monosyllabic words, ten rhyming and ten non-rhyming, which were presented auditorily. The five words in each rhyming string had the same vowel and the same final consonant, while the items in the non-rhyming string had all different vowels and a different final consonant. Word frequency, phonetic structure, and word length were strictly controlled for both conditions. Brady et al. (1983) expected that skilled readers, compared to less skilled, would find recall of rhyming sequences more difficult than non-rhyming sequences, reflecting more efficient use of phonetic code in short-term memory. Skilled readers tend to be strongly affected by rhyme; less skilled readers, however, are less affected by rhyme. Brady et al. (1983) hypothesized that a failure to fully exploit phonetic coding may account for some of the deficits exhibited by less skilled readers. Their study investigated whether a failure to exploit phonetic encoding may be related to speech perception abilities.

Brady et al. (1983) scored items as being correct if they were accurately reported and in the appropriate serial position. The second scoring procedure counted all correct responses regardless of order of report. The error responses for the lists of words were also qualitatively analyzed for transposition errors in relation to the phonetic structure of stimulus words. In analysing the transposition errors, the investigators noted that the recall problems of less skilled readers applied not only to the order of stimuli in a string but also the retention of phonemic sequences in individual words. Many errors consisted of the recombination of phonetic segments that were present in the string of words. As expected, overall accuracy of recall was higher for skilled readers than for less skilled readers. There was a significant effect of list type; as predicted, skilled readers and less skilled readers made fewer errors on non-rhyming word sequences than on rhyming ones. However, less skilled readers recalled fewer items than skilled readers and were less affected by phonetic similarity within a list than were skilled readers. There was a significant interaction between reading group and list type. Skilled readers had better performance in the non-rhyming condition relative to the rhyming condition, where efficient phonetic strategies are beneficial. In contrast, less skilled readers did not show better recall in the non-rhyming condition than in the rhyming condition; they tended to do worse. This finding suggests that less skilled readers may have weaker phonetic coding strategies than skilled readers.

Less skilled readers also produced more errors of transposition in non-rhyming strings and showed greater difficulty preserving the order of words in non-rhyming sequences than skilled readers. Brady et al. (1983) theorized that the greater proportion of transposition errors exhibited by less skilled readers may be a problem that is compounded by difficulties with the preservation of order information within a word. Phonetic error analysis allowed the researchers to determine that less skilled readers did obtain the phonetic information in the stimuli. The greater incidence of transposition errors exhibited by less skilled readers in the non-rhyming condition shows inferior retention of the correct combination of phonetic sequences. This is consistent with past research that has shown that less skilled readers have difficulty preserving serial order information in linguistic tasks, and also emphasizes that the difficulty preserving serial order information extends further to the ordering of phonetic segments within a syllable. Less skilled readers appear to be less affected by the phonetic characteristics of a word. This is consistent with the hypothesis that a failure to use phonetic coding efficiently leads to the less skilled readers' deficit in short-term memory.

To further investigate the origins of the memory coding problems of less skilled readers, Brady et al. (1983) tested the participants on two auditory perception tasks: one involved words (Experiment 2) and the other involved non-speech environmental sounds (Experiment 3). Participants were told that a list of words would be played and were instructed to repeat each item clearly immediately after hearing it. Each task was presented in two conditions, one with a favourable signal-to-noise ratio and one with noise masking. Words of high and low frequency were used as a means of examining whether the differences between readers in the perceptibility of items was due to differences in vocabulary skills. If word frequency interacted with reading achievement level, differences between groups would be attributable to differences in word knowledge rather than problems with the perception of speech. If speech perception skills of poor readers are less effective than those of good readers, word frequency should not show a larger effect on poor readers, as vocabulary skill would not be responsible for the difference in performance on the auditory perception task.

In their second experiment, Brady et al. (1983) investigated the effects of noise on speech perception abilities in skilled and less skilled readers. The perception test consisted of 48 words that were chosen to control for syllable pattern, phonetic composition, and word frequency. In the first listening condition, words were presented at a “comfortable listening level” (approximately 78 Db SPL) with minimal background noise; in the second listening condition, the stimuli were masked with white noise superimposed over the original recording.

Few words in the unmasked condition were missed by either the skilled readers or the less skilled readers, while both groups made considerably more errors in the noise-masked condition. However, less skilled readers made significantly more errors when perceiving the stimuli in the noise-masked condition. Analysis of the error responses showed that the mistakes made by less skilled readers consisted mostly of transpositions of phonetic segments from adjacent syllables. The errors made were rarely semantic. Skilled readers also made transposition errors, but averaged fewer errors than less skilled readers. There was no interaction between word frequency and reading group; thus, the differences between the two reading groups could not be attributed to differences in word knowledge. Brady et al. (1983) argue that this result indicates a problem in the perception of speech. The speech perception skills of less skilled readers are less effective, and this becomes observable when they are required to respond to degraded stimuli.

Experiment 3 was designed to determine whether the difficulties of less skilled readers were the result of a general problem with auditory perception (Brady et al., 1983). Thus, participants were again tested on an auditory perception task, but this time speech processing was not required. Participants were asked to listen to a tape recording of 24 environmental sounds. The 24 stimuli included human nonspeech sounds (coughing), human activities (knocking on a door), mechanical sounds (car starting), musical sounds, animal noises, and nature sounds. Sounds were first presented in noise, and then in a quiet condition. Participants were then asked to identify the source of the sound immediately after hearing it and describe the sound in as much detail as possible. As in the previous experiment, few errors were made when the stimuli were presented in the unmasked condition. With the addition of noise, the performance of both groups once again decreased. However, less skilled readers performed better than skilled readers on the nonspeech task; when age and IQ were controlled for, this effect was not significant.

The comparable performance of the skilled and less skilled readers on the unmasked non-speech task rules out inattention, word frequency, and differences in vocabulary as explanations for the inferior performance on the noise-masked speech perception task. Brady et al. (1983) suggest that the difficulties exhibited by less skilled readers in perceiving speech in noise are specifically related to the processing requirements for speech. Brady argued that the recall of less skilled readers suffers in part from difficulties in perceptual processing. Less skilled readers have greater difficulty perceiving and correctly retaining the phonological representations of words, and this is supported by the pattern of errors they exhibited on the serial recall task.

Speech perception in noise is a strong predictor of reading skills. The addition of noise to a stimulus results in the distortion of speech cues. The research reviewed herein shows that noise appears to influence the recall of less skilled readers to a greater degree than that of skilled readers. For less skilled readers, phonological representations are less stable than the phonological representations of reading age-matched or chronological age-matched groups (Ziegler et al., 2009). Less skilled readers make more errors than skilled readers on serial recall of word strings, suggesting that they have greater difficulty retaining phonetic representations in short-term memory and more difficulty forming phonological representations in long-term memory (Brady et al., 1983). Their speech perception skills are less effective, and in the presence of noise, this deficit is quite apparent. When the perceptual system is stressed by the addition of noise, less skilled readers make significantly more errors when recalling strings of words than skilled readers do (Brady et al., 1983). The addition of noise may indirectly cause the learning of grapheme-phoneme correspondences to become more difficult. Less skilled readers also appear to make inefficient use of phonetic coding in short-term memory. This inefficient use of phonetic coding leads to greater difficulty perceiving and correctly retaining phonological representations. Less skilled readers show weaker effects of phonetic similarity, greater difficulty retaining the order of words, and greater transposition errors of phonetic segments from adjacent syllables, than exhibited by skilled readers (Brady et al., 1983). These studies suggest that less skilled readers require more complete information in order to identify words, and that their phonological representations of words are often weaker than those of skilled readers.

The Role of Echoic Memory in Dyslexia

Echoic memory retains a trace of the most recent speech sounds; when a series of words is presented, the processing of the most recent items continues for a few seconds. The continued processing enables the consolidation of words into long-term memory. If echoic memory is impaired, increased repetitions of a word are required in order to establish a fully-formed phonological representation (Archibald & Gathercole, 2006). Thus, a weakness or inefficiency in echoic memory may be the single critical factor underlying all the phonological deficits that characterize dyslexia. Deficits in echoic memory may therefore contribute to the difficulties in reading acquisition experienced by dyslexics.

Phonological representations in dyslexics

Katz (1986) conducted a two-part study to examine how underlying phonological deficiencies could affect naming, meta-linguistic decisions, and reading. Participants were required to name pictured objects in order to test for the presence of naming deficits. Katz selected 40 items from the Boston Naming Test (BNT; Kaplan, Goodglass, & Weintraub, 1976), based on difficulty rank, frequency, and complexity. On the Boston Naming Test, difficulty level was ranked by the frequency with which naming errors occurred. Participants were divided into reading groups on the basis of their scores on the reading subtest of the Wide Range Achievement Test (WRAT; Jastak & Jastak, 1965). Children with a reading grade level of less than 3.9 were designated as less skilled readers, children with a reading grade level between 4.1 and 5.1 were designated as average, and those who had a reading level above 5.1 were designated as skilled readers.

Less skilled readers named significantly fewer items than did either average or skilled readers. This difference remained when scores were adjusted by eliminating objects that were unfamiliar. Katz found a significant positive relationship between the number of objects a child named and their reading score. Furthermore, there was a significant interaction between difficulty level and reading group. For both skilled and average readers, objects with longs names could be named about as well as those with short names. Less skilled readers showed a decrease in naming accuracy on items with long names, particularly in the difficult group. Less skilled readers also showed lower naming accuracy overall than average and skilled readers. This suggests that less skilled readers may have difficulty accessing phonological representations, particularly those for long and uncommon words, possibly due to difficulties representing and processing items that require greater phonological information.

In a follow-up experiment, Katz (1986) tested skilled and less skilled readers on the adequacy of their phonological representations. Participants were required to complete two tasks: a rhyme task, in which they decided whether two items had rhyming names, and a length task, which required participants to decide which of two objects had the shorter names. Word length was defined by the number of syllables. Items with one- or two- syllable names were defined as short and words with three- or four-syllable names were defined as long. Following the testing on both conditions, participants were shown each test slide and were asked to name the objects to determine if they could retrieve the phonological representations of the test item. Each participant's task performance was assessed using only those trials where both pictured objects had been named correctly.

Katz (1986) reported a weak relationship between reading ability and performance on the rhyme task, but a strong relationship between performance on reading ability and the length task. Less skilled readers were significantly inferior to skilled readers in judging the relative lengths for the names of objects. The finding that less skilled readers had difficulty making length assessments even when they could name the object, suggests that they had difficulty processing the stored phonological information. Katz (1986) suggested that less skilled readers may have greater difficulty than skilled readers in making explicit the word length information that is specified in a phonological representation. This difficulty may arise from phonological representations that are poorly developed. Moreover, less skilled readers lack explicit awareness of the phonological properties of words, even when they are familiar words. They have difficulty processing the stored phonological information; therefore, the performance of less skilled readers suffers when forced to rely solely on the phonological representations stored in long-term memory. Katz argued that the naming errors exhibited by less skilled readers are consistent with many findings that implicate phonological immaturity and deficient processing. The error responses of less skilled readers showed strong phonetic resemblance to the correct names, and were particularly marked on low frequency and polysyllabic items. Less skilled readers were also inferior to skilled readers in judging the relative lengths of names of objects. For less skilled readers, phonological representations may be difficult to access due to a deficiency in representing the full segmental structure of words. With longer names, there is more phonological information that needs to be retrieved.

Katz's (1986) research is consistent with Ziegler et al.'s (2009) findings that the phonological representations of dyslexics are less stable than those of skilled readers, and an encoding process that is more vulnerable to interference from noise. Less skilled readers are less affected by phonetic similarity within a list, and make more transposition errors than skilled readers when recalling sequences of words (Brady et al., 1983). Katz (1986) suggests that the phonological representations of words in skilled readers may be more elaborate than in less skilled readers, allowing skilled readers to name objects with greater ease and accuracy than less skilled readers. This reasoning was supported by performance on the naming task, as there was a significant interaction between reading group and difficulty level, suggesting less skilled readers experience greater difficulty retrieving phonological representations than skilled readers. Katz (1986) suggested that less skilled readers may have phonological deficiencies that underlie the observed naming deficits.

Swan and Goswami (1997) built upon Katz's (1986) work by assessing picture and word naming performance in developmental dyslexics. Their purpose was to assess the phonological properties of picture naming errors in detail and to examine the specificity of these deficits. They compared the performance of developmental dyslexics to that of less skilled readers and three control groups: non-dyslexic poor readers, reading-age matched poor readers, and chronological age-matched readers. Word length and frequency were varied. The picture-naming task consisted of 40 familiar names, 20 monosyllabic words, and 20 words of three to five syllables. Half the names in each category were high-frequency and half were low-frequency words. Participants were also required to complete a measure of receptive vocabulary, which required selecting one of four pictures to match with a spoken word (British Picture Vocabulary Scale, short form, 1982). Following Katz's procedure on the picture naming task (1986), each participant's familiarity with incorrectly named objects was evaluated so that unfamiliar objects would not affect the participant's score. Pilot testing was used to confirm that all pictured objects were familiar to most participants. Familiarity was evaluated after a participant failed to name an item correctly; the participant was questioned about the pictured object's uses or where it had been seen before.

The error data revealed that all groups experienced an effect of word frequency with high-frequency pictures named more easily than low-frequency pictures (Swan &

Goswami, 1997). Dyslexics performed better than less skilled readers on high-frequency items, and their performance was equivalent to less skilled readers on low-frequency items. Dyslexics named fewer items than reading age-matched and chronological age-matched controls, as did less skilled readers. This indicates that the picture naming deficit is not specific to dyslexics. However, dyslexics were more likely than all comparison groups to recognize target names that they failed to identify in the picture-naming tasks. This finding that dyslexics have a unique difficulty in the retrieval of known names suggests a selective difficulty in retrieving phonological codes of those items on demand. Dyslexics were also the only group to make significantly more errors on pictures with long names than on those with short names.

Swan and Goswami (1997) proposed two contributing factors to these picture-naming errors. The first contributing factor relates to a difficulty in the retrieval of known names, while the second contributing factor stems from a lack of target names in the dyslexics' vocabularies; the latter factor, a lack of target names, is also common in less skilled readers. However, the first contributing factor, a selective retrieval problem for phonological representations, is unique to dyslexics. Dyslexics showed difficulty retrieving names that were already in their mental lexicon. The picture naming deficit exhibited by dyslexics was more severe than their age or reading level predicted, and was most evident on phonologically complex names. Swan and Goswami argued that this effect could arise from difficulties either in encoding the full segmental phonological representation or in processing the representations to generate the name on demand. This reasoning is supported by the phonological similarity between the errors and the target items, in addition to the larger percentage of phonological nonword errors made by dyslexics relative to comparison groups.

These two underlying problems in encoding and processing phonological representations are reflected in a number of consequences. Dyslexics demonstrate greater difficulty retrieving the names of pictures with long names, as longer names require more phonological information to be specified and retrieved. For low-frequency items, dyslexics lack sufficient exposure to enable them to encode and develop complete phonological representations. Compared to the errors of less skilled readers and control groups, naming deficits of dyslexics were most evident on phonologically complex names (i.e., long and low-frequency items), and naming errors were more likely to be phonologically similar to the target items than the errors made by less skilled readers or control groups (Katz, 1986; Swan & Goswami, 1997). Naming errors made by dyslexics appear to be uniquely due to deficiencies with encoding and retrieving phonological representations.

Fowler and Swainson (2004) investigated how phonological representations of words in children's oral lexicon differed between skilled and less skilled readers at the onset of schooling and several years following reading instruction. First- and fourth-grade students were tested on measures of reading ability in order to identify extreme groups of skilled and less skilled readers. These students were compared on measures of receptive vocabulary, expressive naming, nonword repetition, and long-term memory. The researchers also assessed item familiarity by including items from the expressive naming task in their measure of receptive name recognition. Participants were also compared on acceptability judgments for variants of object names, imitation, and correction of naming errors by another speaker. The researchers examined how phonological representations differed between good and poor readers and examined the relationship between naming difficulties and verbal memory skills.

Fowler and Swainson's findings (2004) indicate that for both skilled and less skilled readers, imprecise phonological representations, especially for long words, contributed to children's difficulties on all naming tasks. Accuracy for expressive naming was higher for skilled readers than for less skilled readers, and higher for fourth-graders than for first-graders. The researchers also determined that less skilled readers were impaired in their expressive naming of words, even when they visually recognized the item during the receptive vocabulary task. Naming measures correlated moderately with verbal memory and receptive vocabulary scores, and naming performance was strongly associated with reading ability. The results also showed that performance on expressive naming significantly contributed to the prediction of reading level for both age groups. For first-grade students, reader group differences were equally large regardless of item frequency or length. Among fourth-grade students, skilled readers strongly outperformed less skilled readers on the most difficult words. Fourth-grade less skilled readers exhibited difficulties in expressive naming on long, high-frequency items. Overall, less skilled readers performed worse than skilled readers at naming both high- and low-frequency words, and they also demonstrated lower accuracy on the nonword repetition task. However, interactions of word frequency with reading skill were not obtained.

Fowler and Swainson (2004) suggested that the development of phonological representations in the mental lexicon is delayed for less skilled readers. The difficulties exhibited by less skilled readers on the naming and memory tasks were evident during the early stages of learning how to read, as well as several years following reading instruction. Less skilled readers have fewer fully-developed phonological representations, regardless of age level. This research suggests that for less skilled readers, the phonological information may be stored but not retrievable, or stored and retrievable, but it may be incomplete or indistinct for incorrect naming responses.

While semantic attributes of memory representations are fully formed, the phonological representations of less skilled readers are poorly specified or inaccessible. Performance on expressive naming tasks provides support for the hypothesis that the phonological representations of dyslexics are deficient. Name production deficits in dyslexics exist as a result of phonological representations that are ill-specified (Fowler & Swainson, 2004; Katz, 1986), and incorrect naming responses made by dyslexics reflect this conclusion. Dyslexics are more likely to commit naming errors on pictures with long names than those with short names (Swan & Goswami, 1997), and incorrect naming responses by dyslexics are often phonologically similar to the target item (Brady et al., 1983). This indicates that dyslexics do retrieve the phonological representation for recall, but the quality of the phonological representation may be incomplete or impoverished, especially when compared to skilled readers. These deficient phonological representations increase the difficulty of name production even when the target item is familiar. Greater repetition is necessary in order for the phonological representation to be complete, accurate, and connected to a semantic representation. This process requires more time in dyslexics, and as a result, these weak connections cause retrieval difficulties. Incomplete phonological representations translate into difficulties learning grapheme-phoneme correspondences and difficulty segmenting words into phonemes. Finally, these deficiencies result in slower acquisition of literacy skills and word knowledge.

Weakness on nonword repetition and expressive naming tasks indicate that less skilled readers have difficulties forming strong phonological representations, thereby contributing to the vocabulary deficits that are associated with reading disabilities. Less skilled readers may require greater exposure to words in order to develop an adequate phonological representation, a requirement that may slow the process of vocabulary acquisition. For acceptability judgments, less skilled readers tolerated more phonological variation in the production of longer words. On the imitation and correction of naming errors task, less skilled readers were less successful and required more effort than skilled readers. In contrast, skilled readers were more likely to judge only words that were correctly pronounced as acceptable. These findings are consistent with the idea that the development of phonological representations in less skilled readers may be delayed, and this delay results from incomplete phonological representations that provide an insufficient basis for making metalinguistic judgements about the length or pronunciations of words.

For less skilled readers, a deficient A code is a possible cause of impoverished phonological representations. Less skilled readers appear to suffer from an echoic memory with reduced capacity (Gillam, Cowan, & Day, 1995), greater susceptibility to interference (Suprenant, 1999; Ziegler et al., 2009), and faster decay (Sipe & Engle, 1986). If the echoic memory trace does not last long enough, less skilled readers may not have enough time to establish a long-term representation of the words before the echoic memory trace is lost. As a result of inefficient echoic memory processes, less skilled readers would require greater repetition and more exposure to words than skilled readers in order to develop phonological representations that are accurate and retrievable.

Significance of the Study

Research has been reviewed here that demonstrates that echoic information does not persist as long in less skilled readers as it does in skilled readers (Penney & Godsell, 1999). Less skilled readers tend to display larger suffix effects that those seen in skilled readers (Gillam, Cowan, & Day, 1995; Sipe & Engle, 1986), indicating greater vulnerability to interference. Less skilled readers also have greater difficulty than skilled readers when perceiving words in noise-masked conditions and are more prone to phonetic errors (Brady et al., 1983). Dyslexic children are more affected than non-dyslexic children by noise, and experience greater difficulty perceiving the differences in phonemes when noise is present (Ziegler et al., 2005; Ziegler et al., 2009). Dyslexics have imprecise phonological representations, and the difficulty in creating, retrieving and using phonological representations may be due in part to a less robust echoic memory (Fowler & Swainson, 2004)

The poorer level of performance exhibited by dyslexics and less skilled readers may result from an echoic memory that is more vulnerable to interference, has a smaller capacity, or decays faster than the echoic memory of skilled readers. These deficiencies in echoic memory mean that less skilled readers will require a greater number of presentations of a word than skilled readers such that a permanent, accurate, complete, and retrievable representation is formed in long-term memory.

The purpose of the current study is to investigate whether less skilled readers suffer from a deficit in echoic memory that may contribute to their low level of reading achievement. Previous research has suggested that less skilled readers have a less robust echoic memory than skilled readers. In the present research the differences in echoic memory in skilled and less skilled readers were explored through tasks such as serial recall and nonword repetition. Reading skill was measured by performance on the Word Identification subtest of the Woodcock Reading Mastery Test, and skilled and less skilled readers were divided by means of a median split. Serial recall performance was assessed under auditory, visual, and noisy presentation conditions, in order to determine the differences between reading groups in terms of the capacity and vulnerability of echoic memory.

The central hypothesis of the study is that less skilled readers have less efficient echoic memory or echoic memory with less capacity than skilled readers. This hypothesis leads to three predictions. First, less skilled readers should exhibit smaller modality effects than skilled readers due to less benefit from auditory presentation. Second, the memory of less skilled readers will be more vulnerable to noise. Third, nonword repetition performance will be more challenging for less skilled readers than for skilled readers, especially for complex words. Less skilled readers are expected to show lower performance than skilled readers as a result of a weaker echoic memory and the consequent formation of imprecise phonological representations.

Previous research has shown that skilled readers demonstrate a typical modality effect with higher recall of auditory than visual items from the last three serial positions (Penney & Godsell, 1999). Less skilled readers showed a typical modality effect on the last item, but a reverse modality effect occurred for items prior to the final item. The presence of the typical modality effect on the terminal item indicates that less-skilled readers do have a functioning echoic memory, but the reverse modality effect on items preceding the terminal item suggests that they may suffer from impaired echoic memory (Penney & Godsell, 1999).

In the study described here, skilled and less skilled readers were compared on their recall of auditory and visual items. A main effect of reading achievement was expected, less skilled readers were expected to have worse recall overall than skilled readers. Less skilled readers were also predicted to exhibit a smaller effect of presentation modality, due to less benefit from auditory presentation. Auditory presentation was predicted to result in higher performance than visual presentation, and recency positions were expected to be recalled better than primacy positions. Interactions should be found between reading achievement and presentation modality and also between serial position and presentation modality. The interaction between reading achievement and presentation should show a larger benefit from auditory presentation for the better readers. The interaction between serial position and presentation modality should show higher recall for auditory presentation than visual presentation for the recency portion of the serial position curve. A three-way interaction was also predicted between reading achievement, presentation modality and serial position. Skilled readers should show greater benefit than less skilled readers from auditory presentation over the recency portion of the serial position curve.

Research on the effects of noise has shown that encoding a phonological representation becomes more difficult in the presence of noise. Noise distorts cues and disrupts the process of integrating acoustic features into phonological representations, in turn leading to poor access to phonological representations and a lack of speech robustness (Ziegler et al., 2009). Past research has suggested that noise has a greater influence on less skilled readers than skilled readers, resulting in phonological representations that are less stable than the phonological representations of comparison groups. Surprenant (1999) suggested that noise acts like a secondary task; its presence degrades the information received, and renders it less useful. If the echoic memory of less skilled readers is more vulnerable than skilled readers, this noise effect will be reflected in weaker phonological representations and larger decrements in recall. The serial recall of skilled and less skilled readers was compared in auditory and noisy conditions. Less skilled readers were expected to be more affected by noise than skilled readers were. Skilled readers were expected to show stronger recall performance than less skilled readers, and auditory presentation was expected to yield higher recall than noisy presentation. The recency portion of the serial position curve was expected to show a greater effect of noise than earlier serial positions. Reading achievement was expected to interact with noise condition; less skilled readers were expected to show a larger effect of noise than skilled readers. Reading achievement was expected to interact with noise and serial position. If the echoic memory of less skilled readers is deficient, less skilled readers should show a stronger effect of noise than skilled readers over the recency position of the serial position curve.

Current research suggests that poor phonological representations may underlie the difficulties that less skilled readers exhibit on phonological tasks. As a result of difficulties encoding and retrieving phonological representations, less skilled readers achieve lower accuracy and exert greater effort than skilled readers when engaged in expressive naming tasks (Katz, 1986). The development of phonological representations in the mental lexicon seems to be delayed for less skilled readers (Fowler & Swainson, 2004).

Nonword repetition reflects the ability to encode and reproduce novel phonological stimuli (Archibald & Gathercole, 2006). If nonword repetition provides a reflection of the participant's echoic memory processes, there should be differences in performance between skilled and less skilled readers. Therefore, the current study predicts that less skilled readers should make more errors on the nonword repetition task than skilled readers as a result of a weaker echoic memory. Main effects were predicted for reading achievement level, word length, and word complexity. Furthermore, interactions should exist between reading achievement and word complexity, reading achievement and word length, and word length and word complexity. Skilled readers were expected to perform better than less skilled readers on nonword repetition performance; nonwords with consonant clusters were expected to be repeated with less accuracy than items without consonant clusters, and shorter nonwords were expected to be repeated with greater accuracy than longer nonwords. Both reading groups were expected to show higher average performance on low complexity nonwords than on high complexity nonwords. Correct repetitions were expected to decrease as the number of syllables and consonant clusters increase. There should be an interaction between word length and complexity, and also a three-way interaction between reading achievement, word length and word complexity. Less skilled readers were expected to show a larger effect of word length and word complexity than skilled readers as a result of a less efficient echoic memory.

METHOD

Participants

Ethical consent was obtained from the Eastern School District and the researcher received support from principals at local elementary schools in the St. John’s area. In addition, children from local summer programs were invited to participate. Information sheets for parents were sent to local elementary schools and summer programs (see Appendix A). The information sheet detailed how parents could involve their children, and the purpose and procedure of the experiment was provided. Participation was voluntary and none of the participants were paid to participate in this study. The child’s parent or guardian was also required to sign a consent form on their behalf. The treatment of participants was consistent with ethical guidelines as outlined by the Tri-Council policy statement on ethical conduct for research involving humans. A copy of the approval forms required for this study is given in Appendix A. A total of 46 children were initially recruited to participate, but one child did not complete all tests as a result of being unavailable for follow-up. Therefore, the data used in the final analyses is based on a sample of 45 children.

This study included 24 female participants and 21 male participants who were attending summer programs and local elementary schools in St. John’s, Newfoundland. Participants with a range of reading ability were recruited from children between the ages of 6 and 9. The students ranged in age from 6.9 years old to 9.6 years old with a mean age of 8.3 years old. Students were classified as being skilled or less skilled readers on the basis of their scores on the Word Identification subtest of the Woodcock-Johnson Battery. For all analyses reported here, a median split on Word Identification scores was used such that 21 students with raw scores of 59 or greater were classed as skilled readers, and 24 students with raw scores lower than 59 were classed as less skilled readers. The group of less skilled readers included 12 males and 12 females, while 9 males and 12 females comprised the group of skilled readers.

Procedure

Testing was completed in the summer and fall semesters of the 2011 academic year. The researcher visited elementary schools in St. John’s and tested children at their respective elementary schools. Before testing began, the researcher spent a few moments conversing with the child to help them feel at ease. All students were tested individually in two sessions that lasted approximately 45 minutes. Students were tested in quiet areas of the school that were free from distraction, such as resource rooms, staff offices, or empty classrooms. Students from summer programs were tested within normal hours of operation, and students from local elementary schools were tested during regular school hours. All students received a written summary of their performance on the reading achievement measure.

Measures

The Word Identification subtest of the Woodcock Reading Mastery test (WRMT; Woodcock, 1987) was administered to all participants. The Word Identification subtest required the child to read isolated words that increase in difficulty, beginning with words typically presented in early reading. Participants began at the level suggested for their grade, and instructions in the manual Woodcock Reading Mastery Test manual were followed. The Woodcock Reading Mastery test has strong test-retest reliability, with all figures being in the range of 0.80 to 0.90. The Word Identification subtest has an internal consistency of 0.94 and a test-retest reliability of 0.95.

Following the word identification task, participants completed a nonword repetition task. The Children's Test of Nonword Repetition (CNRep) (Gathercole et al., 1994) consists of 40 items between two and five syllables in length, divided into two subsets (n = 20) of nonwords that were classified as high or low complexity. Participants were asked to repeat the lists of two-, three- and four-syllable nonwords. Five syllable nonwords were not tested. Testing included 30 nonwords: 15 items were classified as high complexity (containing consonant clusters) and 15 nonword items were low complexity. Nonwords were presented auditorily using a computerized language analysis program (CLAN), and participants were asked to repeat the nonword after item presentation. Repetition attempts were scored as incorrect if any phonological errors were made. Performance on the nonword repetition task was audio-recorded for later scoring.

Upon completion of the nonword repetition task, participants completed a digit span assessment task. For the digit span task, three lists of three, four, five and six random numbers were presented auditorily. Testing began with the shortest list, and if the participant succeeded on two successive trials of the same length, the next list length was administered. If an error was made, the child was given a second attempt at the sequence. The test was discontinued when the child failed two trials of any digit series (see Appendix B for measures).

Once span length was determined, the participant completed the span-plus-one task. The span-plus-one task consisted of 10 serial recall trials that were conducted in three different presentation modalities: auditory presentation, auditory presentation with white noise, and visual presentation. The number of digits in the list was the basal memory span (determined through span assessment) plus one item to ensure a challenging, but not overwhelming, level of difficulty. Presentation conditions were counterbalanced for six possible orders of presentation (Auditory-Visual-Noise (AVN), ANV, VNA, NAV- and NVA). Participants were assigned to one of six orders of presentation. Eight participants were assigned to each of the conditions AVN, ANV, and VAN, and seven participants were assigned to each of the NVA, NAV and VNA conditions.

In the auditory condition, an auditory recording of a list of random numbers was played using a pre-recorded human voice at a rate of one item per second. In the auditory plus noise condition, similar lists were heard, but noise was added. In the visual condition, the participant viewed digits presented on a computer screen using Microsoft Powerpoint. Each presentation condition included ten lists of digits, which were adjusted for the participant's span length. Participants were asked to concentrate on the digits and then to verbally recall the numbers in their original sequence immediately after they had been presented. Responses were written down by the experimenter.

RESULTS

Students were classified as skilled or less skilled readers on the basis of raw scores on the Word Identification subtest of the Woodcock Reading Mastery Test. For all analyses reported here, a median split on Word Identification scores was used such that 21 students with raw scores of less than 59 were classified as less skilled readers, and 24 students with scores of 59 or greater were classed as skilled readers. For the less skilled readers, standard scores on the Word Identification subtest had mean of 99.8 (SD = 11.5); standard scores for skilled readers had a mean of 117.8 (SD = 8.8).

Prediction 1

The central hypothesis of this study is that less skilled readers have less efficient echoic memory or echoic memory with less capacity and greater susceptibility to interference than do children who are skilled readers. The first prediction of this hypothesis is that less skilled readers will show a smaller benefit of auditory presentation in the serial recall task than skilled readers due to an echoic memory that functions less efficiently. Main effects were predicted for reading achievement, presentation modality, serial position, and interactions were expected between presentation modality and serial position, and between reading group and presentation modality. A three-way interaction was also expected between reading achievement, presentation modality, and serial position. The size of the modality effect was expected to be larger for skilled readers than less skilled readers over the final two serial positions.

Past research has shown that less skilled readers perform poorly on memory span tasks compared with skilled readers; therefore, it was expected that less skilled readers would perform more poorly on digit span regardless of presentation modality. If less skilled readers suffer from a deficit in echoic memory, as predicted, an interaction between reading skill and presentation modality should take place. Less skilled readers should demonstrate a much smaller modality effect than skilled readers or no modality effect at all. It was expected that the benefits of auditory presentation would be larger for skilled readers than for less skilled readers.

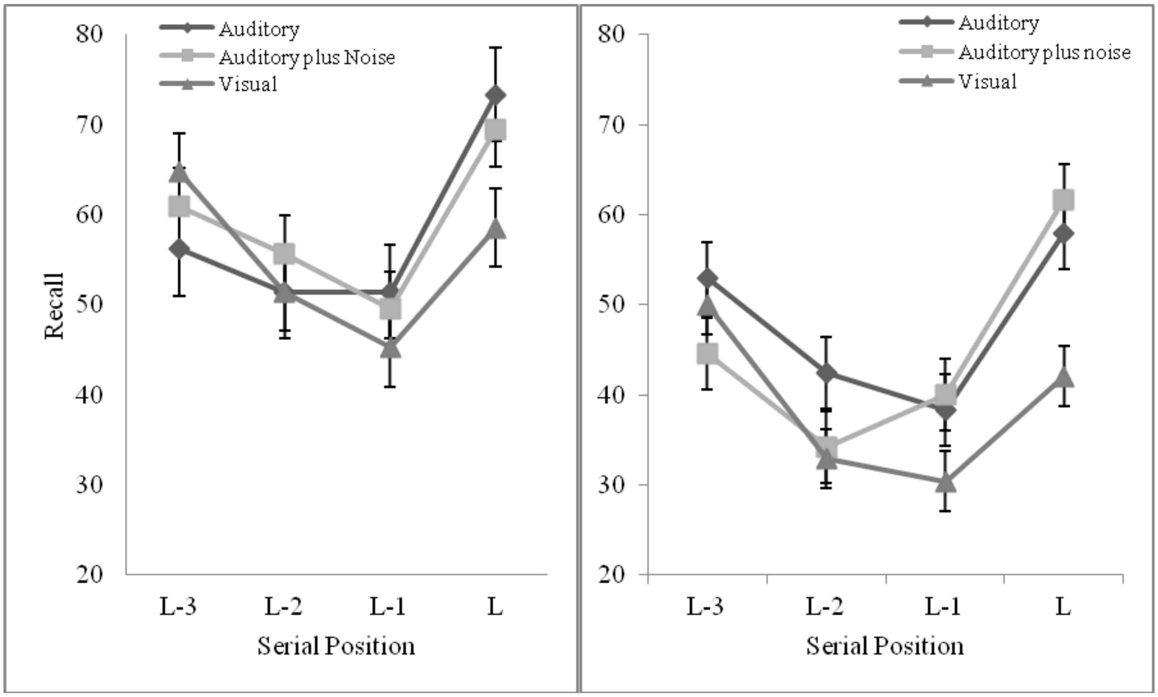

Figure 1. Performance of skilled readers (left panel) and less-skilled readers (right panel) on serial recall as a function of presentation modality and serial position. Points represent mean recall; vertical lines depict standard error of the means.

A 2 × 2 × 4 repeated measures analysis of variance was conducted to analyze the effect of reading achievement and presentation modality on serial recall performance. The statistical significance of effects was evaluated with repeated measures analyses of variance, incorporating the Greenhouse–Geisser correction for violations of sphericity. The within-subjects variables were presentation modality (auditory and visual) and serial position accuracy for the last four digits recalled. The between-subjects variable was reading group. Recall was measured by the percentage of items recalled correctly and in the correct serial position.

The main effect of reading achievement was significant, F (1, 43) = 4.33, $p < .05$. Skilled readers showed higher average recall than less skilled readers regardless of presentation modality (see Figure 1). There was also a significant main effect of serial position, F (1.86, 80.1) = 21.5, $p < .01$. Figure 1 shows that for auditory and visual serial recall, both skilled and less skilled readers demonstrated strong primacy and recency effects. The interactions between reading achievement and presentation modality and between reading achievement and serial position were not significant.

The main effect of presentation modality was not quite significant, F (1, 43) = 3.56, $p = 0.07$. However, the interaction between presentation modality and serial position was significant, F (1.84, 79.1) = 7.40, $p < .01$. Figure 1 shows the typical modality effect for skilled and less skilled readers with higher recall of the last two auditory serial positions than the corresponding visual digits. As predicted, the modality effects observed for serial positions L-1 and L were consistent with those reported in earlier literature, showing a large recency effect for auditory items.

Figure 1 shows that the modality effect was largest over the last two serial positions, for both skilled and less skilled readers. Therefore, these serial positions were assessed in the following analysis. In order to further explore differences in performance between skilled and less skilled readers, a 2 × 2 analysis of variance was conducted on the final two items in the list. The independent variable was reading level, and the dependent variable was the percentage of items correctly recalled in the correct serial position for the terminal and pre-terminal serial positions (L and L-1).

As expected, there was a significant main effect for reading achievement, F (1, 86) = 7.53, $p < .01$. Skilled readers performed better than less skilled readers on both auditory and visual serial recall. For skilled readers, average auditory serial recall performance (M = 58.1, SD = 26.0) was higher than average visual serial recall performance (M = 55, SD = 26.5). Performance for less skilled readers was also higher for auditory serial recall (M = 47.9, SD = 23.3) than for visual serial recall performance (M = 38.9, SD = 19.2). There was also a main effect for presentation modality, F (1, 86) = 4.20, $p < .05$, with both groups demonstrating higher recall after auditory presentation than after visual presentation. It was also predicted that reading achievement and presentation modality would interact, but there was no significant interaction between presentation modality and reading achievement, $F < 1$. Therefore, there is no evidence to suggest that reading achievement level interacts with presentation modality to influence the level of serial recall. However, these results do support previous research showing superior recall for auditory over visual presentation.

Prediction 2

The second prediction of the study is that echoic memory will be more susceptible to auditory interference in less skilled readers than in skilled readers. Past research has suggested that echoic memory is more vulnerable to interference for less skilled readers than the echoic memory of skilled readers (Gillam et al., 1995; Sipe & Engle, 1986). Penney and Godsell's (1999) finding of an interaction between reading achievement and presentation modality has not been replicated, but this failure to replicate may be due to their use of slightly noisy stimuli. If the echoic memory of less skilled readers is more susceptible to noise than the echoic memory of skilled readers, noise should cause a larger effect in less skilled readers. Significant main effects were predicted for reading achievement, noise condition, serial position, as well as an interaction between reading achievement and noise. If less skilled readers are more vulnerable to interference from noise than skilled readers, reduced recall under noise conditions would confirm that their memory is more susceptible to interference. If echoic memory is responsible for this deficit, the effect of noise should be seen over the final serial positions.

Figure 1 shows that the noise effect appears mainly at serial positions L-3 and L-2, rather than on the final two serial positions. Therefore, the percentage accuracy of recall performance for these serial positions was assessed in a 2 × 2 × 2 analysis of variance; within-subjects variables were noise (auditory presentation with or without accompanying noise) and serial positions L-3 and L-2. The between subjects variable was reading achievement level.

Skilled readers did show higher average recall than less skilled readers; however, the main effect of reading achievement was not quite significant, F (1, 43) = 3.53, $p = 0.07$. However, there was a significant main effect for serial position, F (1, 43) = 18.78, p = 0.05), with both groups of participants showing a strong primacy effect at serial position L-3. Serial position did not interact significantly interact with reading level or noise condition. The three-way interaction between serial position, reading level and noise condition was also not significant.

The main effect of noise did not reach significance, $F < 1$. However, there was a significant interaction between noise condition and reading achievement, F (1, 43) = 4.02, $p < .05$. For skilled readers, recall was not impaired by the presence of noise. However, in the noise condition, the performance of less skilled readers on serial positions L-3 (M = 44.6, SD = 27.2) and L-2 (M = 34.2, SD = 24.5) was lower than their performance on auditory serial recall for L-3 (M = 52.9, SD = 26.0) and L-2 (M = 42.5, SD = 24.2). The size of the noise effect was significantly larger for less skilled readers (M = 16.7, SD= 39.2) than for skilled readers (M = -9.05, SD = 46.9).

If less skilled readers are more vulnerable to noise as a result of echoic memory deficits, it was hypothesized that the recency portion of the serial position curve should show the greatest impact of noise, similar to the modality effect. However, the greater impact of noise was seen over the serial positions L-3 and L-2, rather than the final serial positions (see Figure 1). This finding is not consistent with the hypothesis that less skilled readers would suffer from a greater effect of noise due to echoic memory deficits.

However, this finding is consistent with previous research by Surprenant (1999) on the effect of noise on memory for spoken syllables.

Surprenant's (1999) research on memory found substantial effects of noise at the beginning of the serial position curve. If listeners rely solely on modality-independent features there should not be an effect of noise at the beginning of the serial position curve. Surprenant (1999) argued that an effect of noise on early serial positions indicates that noise acts as a secondary task. The data reported here also shows that noise has a larger impact on earlier serial positions, causing a measurable decrement in recall, and potentially imposing a secondary task which may affect resource allocation when speech needs to be understood.

The significant interaction between reading skill and noise condition offers limited support for the hypothesis that less skilled readers would be more susceptible to noise than skilled readers due to echoic memory impairment. However, noise does appear to impact less skilled readers to a greater degree than skilled readers and created a measurable decrement in recall over early serial positions. The decrease in recall over early serial positions supports Surprenant's (1999) argument of noise acting as a secondary task.

Prediction 3

The third prediction asserts that if echoic memory is somehow deficient in less skilled readers, performance on the nonword repetition task will be poorer in less skilled readers than skilled readers. Previous research has suggested that the development of phonological representations in the mental lexicon is delayed in less skilled readers

(Fowler & Swainson, 2004). Nonword repetition was hypothesized to be a measure that taps the echoic memory differences that predispose children to have difficulty acquiring language skills (Archibald, 2008). If echoic memory is impaired, increased repetitions of a word are required in order to establish a fully-formed phonological representation. If less skilled readers suffer from an impaired echoic memory, their performance on the nonword repetition task should be lower than the performance of skilled readers. If less skilled readers suffer from impairment in echoic memory, a main effect should be seen for reading achievement. Main effects were predicted for word length and complexity, with repetition being worse for longer words and on words with consonant clusters. An interaction between word length and complexity was expected; both reading groups were expected to show higher performance on low-complexity nonwords than on high-complexity nonwords. Reading achievement was expected to interact with both word length and word complexity. If less skilled readers have a diminished capacity for preserving fully-formed phonological representations as a result of impairments in echoic memory, their nonword repetition performance should show a larger effect of word complexity and word length than skilled readers.

A three-way interaction was also predicted to occur between reading achievement, word complexity, and word length. If less skilled readers suffer from a deficit in echoic memory, nonword repetition accuracy should be more difficult for less skilled readers than skilled readers. Both skilled and less skilled readers are expected to show lower repetition accuracy as item complexity and length increase, and the effects of both complexity and word length are predicted to be larger for the less skilled readers.

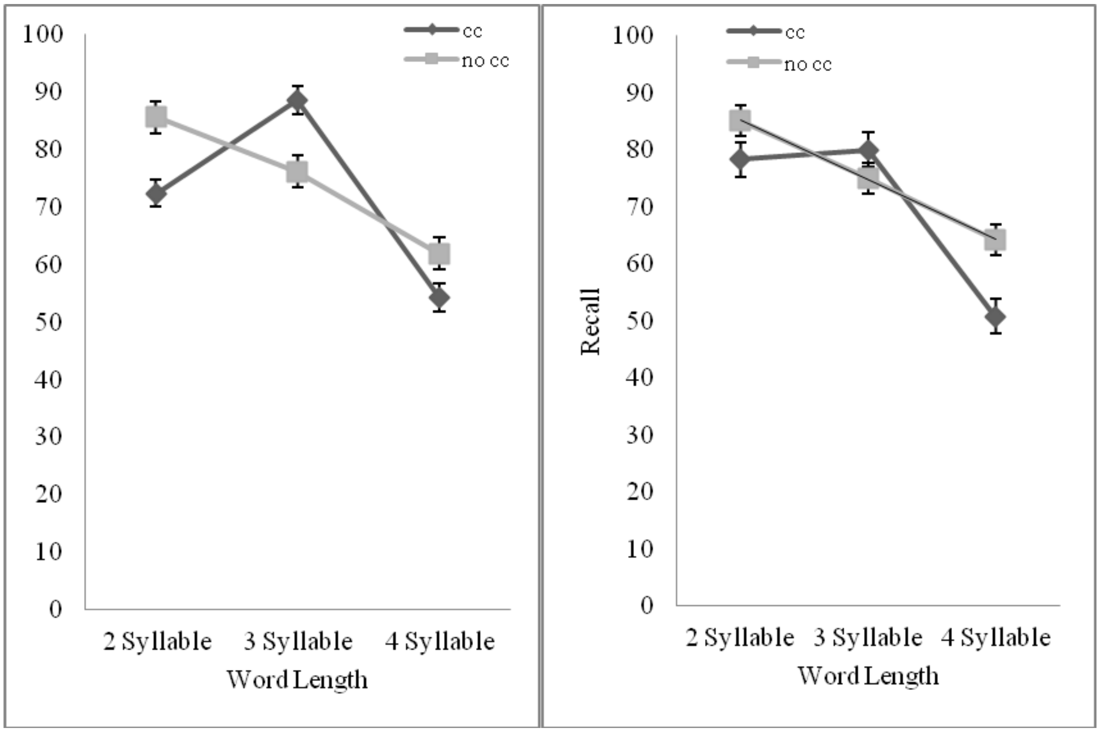

Figure 2. Performance of skilled readers (left panel) and less skilled readers (right panel) on nonword repetition as a function of nonword length and complexity. Performance on high complexity nonwords that contain consonant clusters (CC) is contrasted with performance on low complexity nonwords without consonant clusters (no CC). Points represent mean recall; vertical lines depict standard error of the means.

A 2 × 2 × 3 repeated measures analysis of variance was conducted to compare the performance of skilled and less skilled readers on nonword repetition with the presence or absence of consonant clusters and word length (defined by number of syllables, 2 - 4) as the within-subjects variables. The dependent variable was the percentage of correct repetitions of the nonword stimuli and the independent variable was reading group.

The overall difference between reading groups was not significant, $F < 1$. Skilled and less skilled readers did not show significant differences in performance on the nonword repetition task. This does not support the hypothesis that echoic memory is deficient in less skilled readers. It is possible that nonword repetition does not fully reflect echoic memory processes, as nonword repetition did not correlate with performance on the two most recent serial positions in the auditory serial recall task (r (45) = .32, $p > .05$). The modality effect reflects echoic memory. The finding that nonword repetition did not show a strong association with the modality effect suggests that nonword repetition may not be based on echoic memory.

There was a significant main effect of consonant clusters, F (1, 43) = 4.10, $p < .05$. Accuracy on nonword repetition was higher when there were no consonant clusters in the words (see Figure 2). Participants showed higher average performance on low complexity nonwords (M = 74.7, SD = 12.0) than high complexity nonwords (M = 70.1, SD = 13.1). There was also a significant main effect of word length, F (2, 43) = 47.6, $p < .01$, shorter words were repeated with greater accuracy than longer words. Two syllable nonwords were repeated with the highest accuracy (M = 80.2, SD = 9.4), followed by three syllable nonwords (M = 79.8, SD = 15.6), and four-syllable nonwords (M = 58, SD = 18). The interaction between consonant cluster and word length was significant, $F(2, 86) = 10.7$, $p < .01$. These results replicate Gathercole's (1995) findings that as nonwords become longer and more complex, both groups experienced increased difficulty with accurate repetition.

There were no significant interactions between reading skill and word complexity, or between reading skill and word length. There was no significant three-way interaction between reading achievement, word complexity and word length. These findings do not support the prediction that nonword repetition performance is poorer in less skilled readers than in skilled readers.

DISCUSSION

Children's serial recall performance was investigated as a function of reading level and presentation modality, with the intent of understanding echoic memory differences and how they may contribute to reading achievement. The central hypothesis of the study was that less skilled readers would have less efficient echoic memory or echoic memory with less capacity than skilled readers. Three predictions related to this hypothesis were tested. The first prediction was that less skilled readers would show a smaller modality effect than skilled readers, due to less benefit derived from auditory presentation. The hypothesis that echoic memory is more vulnerable to interference in less skilled readers than in skilled readers predicts that noise should have a more detrimental effect on the recall of less skilled readers. If echoic memory is more vulnerable to interference in less skilled readers than in good readers, and if nonsense word repetition is a measure of echoic memory, the third prediction was that performance on nonword repetition would be poorer in less skilled readers than in skilled readers.

The modality effect in serial recall

To test the first prediction, participants were tested on immediate serial recall of numbers that were presented auditorily or visually. If less skilled readers have less echoic memory capacity than skilled readers, a smaller modality effect should be obtained for the last two or three items at the end of a list for the less skilled readers relative to the skilled readers.

The main effect of reader skill confirms that skilled readers perform better than less skilled readers on memory tasks regardless of presentation modality. This finding suggests that less skilled readers have poorer memories overall than skilled readers.

The modality effect was found over the last two serial positions with skilled readers having higher recall than less skilled readers. This finding confirms that both skilled and less skilled readers have a functioning echoic memory.

Both skilled and less skilled readers exhibited the typical modality effect for the final two serial positions but the predicted interaction between reading achievement and presentation modality was not obtained. The failure to provide this interaction provides no evidence to support the prediction that less skilled readers derive less benefit from auditory presentation than do skilled readers.

The noise effect in serial recall

The second prediction was that the recall of less skilled readers would be more vulnerable to interference than the recall of skilled readers. To test the second prediction, participants were tested on immediate serial recall of numbers presented in the auditory modality with or without background noise. If the prediction is correct, less skilled readers will show greater interference from noise than will skilled readers.

There was a significant interaction between noise condition and reading achievement with the recall of less skilled readers showing a greater impact of noise for the medial serial positions L-3 and L-2 than was seen in skilled readers. This finding confirms that the memory of less skilled readers is more vulnerable to interference than the memory of skilled readers.

Echoic memory is inferred from the modality effect which usually affects only the last two to three items in serial recall tasks. However, the data reported here show that less skilled readers showed a greater noise effect than skilled readers at serial positions L-3 and L-2. This finding is not entirely consistent with an interpretation in terms of echoic memory, as the early serial positions were affected rather than the last few serial positions. The data reported here appear to be more consistent with Surprenant's (1999) finding of a substantial noise effect at the beginning of the serial position curve. Surprenant (1999) argued that the effect of noise on early serial positions indicates that noise acts as a secondary task. The data reported here also shows that noise had an impact on early serial positions rather than recency positions, a finding consistent with Surprenant's (1999) interpretation.

Nonword repetition performance and reading achievement

The third prediction arising from the hypothesis that the echoic memory of less skilled readers is less efficient than skilled readers is that less skilled readers will perform more poorly on nonword repetition than skilled readers. Nonword repetition tests the ability to encode and reproduce novel verbal words and is thought to measure echoic memory. If nonword repetition measures echoic memory, skilled readers should have shown stronger performance than less skilled readers, and nonword repetition should have shown a strong correlation with auditory serial recall performance on terminal serial positions.

The main effect of reader skill was not significant on the nonword repetition task. Skilled and less skilled readers did not show significant differences in performance. This does not support the hypothesis that echoic memory is deficient in less skilled readers. However, the association between nonword repetition and auditory serial recall was quite weak. In contrast, performance on auditory, auditory plus noise, and visual serial recall tasks correlated quite strongly with one another. This suggests that nonword repetition and serial recall may reflect different memory processes, and nonword repetition may not be measuring echoic memory.

If less skilled readers had a diminished capacity for preserving fully-formed phonological representations as a result of a deficient echoic memory, their nonword repetition performance should have shown a larger effect of word complexity and word length relative to skilled readers. Both reading groups were equally affected by word length and complexity; each group experienced difficulty repeating longer and more complex nonwords. Reading skill did not interact with word complexity or word length. In addition, there was no significant interaction between reading ability, word complexity and word length. Therefore, there is no evidence to suggest that skilled and less skilled readers differ in the quality of phonological representations, as performance on nonword repetition was similar for both skilled and less skilled readers. These findings do not support the main hypothesis of a weaker echoic memory for less skilled readers than skilled readers.

Conclusions

The research conducted here showed that both skilled and less skilled readers exhibited the typical modality effect, a finding that suggests that both groups have a functioning echoic memory. However, contrary to expectations, less skilled readers did not show a larger modality effect than skilled readers. Less skilled readers did show a larger noise effect than skilled readers. Echoic memory typically affects the last 2-3 items, but the largest effect of noise was not found for these items, but instead occurred for the third and fourth last items. This finding is not consistent with the hypothesis that less skilled readers suffer from a greater effect of noise due to echoic memory deficits.

Performance on the nonword repetition task showed that both skilled and less skilled readers were equally affected by word length and the presence of consonant clusters. No strong evidence was found to support the hypothesis that echoic memory is deficient in poor readers, as there was no effect of reader skill in the nonword repetition task.

Overall, the study did not provide any evidence that echoic memory is deficient in less skilled readers. However, the decrease in recall exhibited by less skilled readers in the presence of noise suggests that there may be differences between skilled and less skilled readers in terms of the vulnerability of memory for speech to interference from white noise. The noise effect data appears to support Surprenant’s (1999) conclusion that the addition of noise creates a secondary task, and reduces short-term recall. The nonword repetition task did not show differences in performance between skilled and less skilled readers, but this task may not fully reflect echoic memory processes.

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Appendix A: Supplementary Documentation

Information About the Study

Title: Are Echoic Memory Processes Linked to Reading Achievement?

Researcher: Rania Malik, Masters Student in Developmental Psychology
Phone: (709) 743-0052
Email: rania.malik@mun.ca

Supervisor: Dr. Catherine Penney, Professor, Dept. of Psychology, Memorial University Phone: (709) 864-7687
Email: cathpenn@mun.ca

The proposal for this research has been reviewed by the Interdisciplinary Committee on Ethics in Human Research and found to be in compliance with Memorial University's ethics policy. If you have ethical concerns about the research (such as the way you have been treated or your rights as a participant), you may contact the Chairperson of the ICEHR at icehr@mun.ca or by telephone at 864-2861.

Your child is invited to take part in a research project entitled "Are Echoic Memory Processes Linked to Reading Achievement?"

This form is part of the process of informed consent. It should give you a basic idea of what the research is about and what your child's participation will involve. If you or your child would like more detail about something mentioned here, you should feel free to ask. Please take the time to read this carefully and to understand any other information given to you by the researcher.

It is entirely up to you and your child to decide whether to take part in this research. If you or your child chooses not to take part in the research or if you or your child decide to withdraw from the research once it has started, there will be no negative consequences for you, now or in the future.

Purpose of the Study

The purpose of this study is to determine if there is any relationship between short-term memory performance and reading achievement.

What you will do in this study?

Participants will hear or see lists of numbers and will be asked to repeat the numbers back in their original order. Recall will be tested under auditory and visual conditions to examine how different modalities influence recall. On some auditory trials there will be noise in the background. Performance on this task will be audio recorded.

Children will be given a subtest from the **Woodcock Reading Mastery test**. The Word Identification subtest requires children to read isolated words.

On the nonword repetition test there are 30 items. Nonwords will be presented auditorily, and participants will be asked to repeat the nonword immediately after it has been presented. Performance on the nonword repetition task will be audio recorded.

Length of time

Testing is expected to take approximately one hour altogether and will be spread over two sessions. Testing will take place during program hours, and children will be called out and tested on site.

Risks and Benefits

There are no particular risks associated with this experiment, other than the mild stress of being tested. A possible benefit is that you will have standardized measures of reading achievement for your child. Consideration will be given to ensure that parents fully understand the results, and researchers will also be available to answer any questions after testing is complete. The researchers may identify undiagnosed reading difficulties. If this occurs, parents will be advised to contact Dr. Penney.

Confidentiality

Only the researcher and supervisor will see the response sheets from the participants. **No information will be given to summer program personnel.** Parents will receive results for their child's standardized tests.

Data will be kept for at least five years after publication in a locked filing cabinet in Dr. Penney's office or storage space. After five years, the files will be destroyed.

Anonymity

Participant response sheets will be identified only by a code number. Only the primary researcher and supervisor will have access to any identifying information.

Recording of Data

The non-word repetition and digit span tasks are the only tasks in which responses are recorded. The purpose of recording this data is to check on scoring. Non-word repetition data may also be analysed later by a linguist. All data files will be anonymous.

Reporting of Results

The researchers hope that in time the study will be published in an academic journal. No individuals will be identified. In any publication, group means and other statistics will be given. After completion of the study, the completed thesis will be sent to every program within the St. John's area that has chosen to participate in the study, such as the Boys and Girls Club, FUNdamentals childcare, and the MUN childcare center.

Questions

Your child is welcome to ask questions at any time during participation in this research. If you or your child has any questions or concerns about this study, or if you wish to receive a copy of the results upon completion of the study, please contact one of the following researchers: Dr. C. Penney (cathpenn@mun.ca) or Rania Malik (rania.malik@mun.ca).

Consent Form

Consent:

Your signature on this form means that:

- You have read the information about the research
- You have been able to ask questions about this study
- You are satisfied with the answers to all of your questions
- You understand what the study is about and what you will be doing
- You understand that you are free to withdraw your child from the study at any time, without having to give a reason, and that doing so will not affect you now or in the future.

If you sign this form, you do not give up your legal rights, and do not release the researchers from their professional responsibilities.

The researcher will give you a copy of this form for your records.

Your Signature:

I have read and understood the description provided; I have had an opportunity to ask questions and my questions have been answered. I consent to participate in the research project, understanding that I may withdraw my consent at any time. I understand that my child will also be asked for their oral consent, and that the study will not proceed without consent from both parties. A copy of this Consent Form has been given to me for my records.

______________________________ ______________________________

Signature of Parent/ Guardian Name of Parent/ Guardian (please print)

____

Date

Researcher's Signature:

I have explained this study to the best of my ability. I invited questions and gave answers. I believe that the participant fully understands what is involved in being in the study, any potential risks of the study and that he or she has freely chosen to be in the study.

_________________________________ _____________________________________

Signature of investigator Date

Telephone: ___________________________

Email address: ________________________

Student's Contact Information

Child's name

____

Last First Middle

Child's Date of Birth

____

School ______________________________Grade____________________

Teacher's Name

____

Mother's Name

____

Father's Name

____

Mailing Address

____

Home Phone Number

____

Work Phone Number (Preferred Contact) ____

Work Phone Number (Second Contact) ____

Mobile Phone Number (Preferred contact) _______________________________________

Home e-mail address ____

Work e-mail Address (Preferred contact) _______________________________________

Work e-mail Address (Second Contact) ____

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Interdisciplinary Committee on
Ethics in Human Research (ICEHR)

Office of Research
St. John's, NL Canada A1C 5S7
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www.mun.ca

ICEHR Number:	**2010/11-139-SC**
Approval Period:	**June 9, 2011 – June 30, 2012**
Sponsor:	-
Responsible Faculty:	**Dr. Catherine Penney** Department of Psychology
Title of Project:	***Are echoic memory processes linked to reading achievement?***

June 9, 2011

Ms. Rania Malik
Department of Psychology
Memorial University of Newfoundland

Dear Ms. Malik:

Thank you for your email correspondence of June 8, 2011 addressing the issues raised by the Interdisciplinary Committee on Ethics in Human Research (ICEHR) concerning the above-named research project.

The ICEHR has re-examined the proposal with the clarification and revisions submitted and is satisfied that concerns raised by the Committee have been adequately addressed. In accordance with the *Tri-Council Policy Statement on Ethical Conduct for Research Involving Humans (TCPS2)*, the project has been granted *full ethics clearance* for <u>one year</u> from the date of this letter.

If you intend to make changes during the course of the project which may give rise to ethical concerns, please forward a description of these changes to Mrs. Brenda Lye at <u>blye@mun.ca</u> for the Committee's consideration.

The *TCPS2* requires that you submit an annual status report on your project to the ICEHR, should the research carry on beyond June 2012. Also to comply with the *TCPS2*, please notify us upon completion on your project.

We wish you success with your research.

Yours sincerely,

Lawrence F. Felt, Ph.D.
Chair, Interdisciplinary Committee on
Ethics in Human Research

LF/en

copy: Supervisor – Dr. Catherine Penney, Department of Psychology

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Interdisciplinary Committee on Ethics in Human Research (ICEHR)

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ICEHR Number:	**2010/11-139-SC**
Approval Period:	**June 9, 2011 – June 30, 2012**
Funding Agency:	-
Responsible Faculty:	**Dr. Catherine Penney** **Department of Psychology**
Title of Project:	***Are echoic memory processes linked to reading achievement?***
Amendment #:	***#01***

September 9, 2011

Ms. Rania Malik
Department of Psychology
Memorial University of Newfoundland

Dear Ms. Malik:

The Interdisciplinary Committee on Ethics in Human Research (ICEHR) has reviewed the proposed addendum as outlined in your correspondence dated September 1, 2011 for the above referenced project, and is pleased to give its approval to include third-grade children attending elementary schools in the St. John's area as participants in your study as requested provided all approved protocols are followed.

If you should make any other changes either in the planning or during the conduct of the research that may affect ethical relations with human participants, please forward a description of these changes to Mrs. Brenda Lye at blye@mun.ca for further review by the Committee.

Your ethics clearance for this project expires June 30, 2012 at which time you must submit an annual status report to ICEHR. Also, to comply with the *Tri-Council Policy Statement on the Ethical Conduct for Research Involving Humans (TCPS2)*, please notify us when research on this project concludes.

The Committee would like to thank you for the update on your proposal and we wish you well with your research.

Yours sincerely,

M Shute

Michael Shute, Th.D.
Chair, Interdisciplinary Committee on
Ethics in Human Research

MS/bl

copy: Supervisor – Dr. Catherine Penney, Department of Psychology

Appendix B: Measures

Nonword Stimuli in the Children's Test of Nonword Repetition:

Two syllable:

Ballop (Low complexity)

Bannow (low complexity)

Diller (low complexity)

Glistow (high complexity)

Hampent (high complexity)

Pennel (low complexity)

Prindle (high complexity)

Rubid (low complexity)

Sladding (high complexity)

Tafflest (high complexity)

Three Syllable:

Bannifer (low complexity)

Barrazon (low complexity)

Brasterer (high complexity)

Commerine (low complexity)

Doppelate (low complexity)

Frescovent (high complexity)

Glistering (high complexity)

Skiticult (high complexity)

Thickery (low complexity)

Trumpetine (high complexity)

Four Syllable:

Blonterstaping (high complexity)

Commeecitate(low complexity)

Contramponist (high complexity)

Empliforvent (high complexity)

Fenneriser (low complexity)

Loddenapish (low complexity)

Pennerriful (low complexity)

Perplisteronk (high complexity)

Stopograttic (high complexity)

Woogalamic (low complexity)

Digit Span Assessment:

Beginning with a three-digit sequence, the participants will hear four lists of a particular length. If an error is made, the child will be given a second attempt at the sequence. If the child fails on two successive trials of the same length, he or she will not be presented with any further sequences of the same length, but with a sequence one item shorter. If the child succeeds on two successive trials of the same length, the next list length will be administered.

First ensure that the child can read digits.

Age 5 ½ to 6: Begin with three digit sequence. If the child fails, give him a second three digit sequence. If the child fails again, give him one or both two digit sequences until he passes them. If the child succeeds on the three digit sequence, go on to the four digit sequence and so on. Discontinue the test when the child fails both trials of any one digit series.

Age 7 to 9: Start with the four digit sequence. If the child fails give one or both two digit sequences. If the child succeeds on the four digit sequence, go to the five digit sequence and so on. Each condition will be terminated when two trials of equal span are not recalled correctly.

2 digit list:

8, 5 __ __

2, 5 __ __

1, 8 __ __

3 digit list:

9, 1, 6 __ __ __

1, 3, 5 __ __ __

9, 2, 4 __ __ __

4 digit list:

9, 6, 1, 8 __ __ __ __

5, 8, 1, 6 __ __ __ __

1, 9, 8, 3 __ __ __ __

5 digit list:

2, 6, 9, 4, 8 __ __ __ __ __

6, 1, 3, 9, 4 __ __ __ __ __

3, 6, 2, 8, 1 __ __ __ __ __

6 digit list:

2, 5, 3, 6, 9, 4 __ __ __ __ __ __

5, 1, 4, 9, 2, 6 __ __ __ __ __ __

3, 6, 4, 1, 9, 2 __ __ __ __ __ __

Span +1 Trials:

3 Digit List: Auditory

Set 1: 5, 8, 1 __ __ __

Set 2: 5, 2, 4 __ __ __

Set 3: 3, 6, 8 __ __ __

Set 4: 6, 9, 1 __ __ __

Set 5: 6, 8, 1 __ __ __

Set 6: 2, 6, 3 __ __ __

Set 7: 4, 1, 3 __ __ __

Set 8: 8, 2, 4 __ __ __

Set 9: 9, 3, 8 __ __ __

Set 10: 1, 9, 3 __ __ __

3 Digit List: Auditory plus Noise

Set 1: 1, 4, 9 __ __ __

Set 2: 5, 1, 9 __ __ __

Set 3: 5, 3, 6 __ __ __

Set 4: 3, 6, 4 __ __ __

Set 5: 1, 9, 6 __ __ __

Set 6: 3, 1, 8 __ __ __

Set 7: 6, 4, 9 __ __ __

Set 8: 2, 6, 4 __ __ __

Set 9: 9, 1, 8 __ __ __

Set 10: 9, 4, 8 __ __ __

3 Digit List: Visual

Set 1: 3, 8, 1 ___ ___ ___

Set 2: 1, 9, 2 ___ ___ ___

Set 3: 3, 6, 2 ___ ___ ___

Set 4: 1, 8, 6 ___ ___ ___

Set 5: 9, 2, 6 ___ ___ ___

Set 6: 6, 3, 1 ___ ___ ___

Set 7: 1, 4, 9 ___ ___ ___

Set 8: 9, 6, 1 ___ ___ ___

Set 9: 3, 2, 8 ___ ___ ___

Set 10: 8, 6, 2 ___ ___ ___

4 Digit List: Auditory

Set 1: 8, 3, 6, 4 __ __ __ __

Set 2: 3, 9, 5, 2 __ __ __ __

Set 3: 4, 9, 6, 1 __ __ __ __

Set 4: 5, 3, 1, 6 __ __ __ __

Set 5: 6, 3, 8, 4 __ __ __ __

Set 6: 9, 4, 8, 6 __ __ __ __

Set 7: 9, 2, 6, 4 __ __ __ __

Set 8: 8, 2, 9, 6 __ __ __ __

Set 9: 3, 6, 2, 9 __ __ __ __

Set 10: 3, 8, 4, 6 __ __ __ __

4 Digit List: Auditory plus Noise

Set 1: 6, 5, 8, 1 __ __ __ __

Set 2: 3, 6, 1, 5 __ __ __ __

Set 3: 5, 9, 6, 3 __ __ __ __

Set 4: 4, 8, 2, 5 __ __ __ __

Set 5: 4, 1, 6, 3 __ __ __ __

Set 6: 2, 4, 9, 6 __ __ __ __

Set 7: 6, 3, 8, 4 __ __ __ __

Set 8: 8, 1, 4, 6 __ __ __ __

Set 9: 1, 9, 2, 5 __ __ __ __

Set 10: 8, 5, 3, 6 __ __ __ __

4 Digit List: Visual

Set 1: 8, 3, 2, 5 __ __ __ __

Set 2: 6, 1, 9, 2 __ __ __ __

Set 3: 8, 6, 4, 1 __ __ __ __

Set 4: 5, 3, 9, 2 __ __ __ __

Set 5: 2, 9, 4, 6 __ __ __ __

Set 6: 4, 3, 6, 8 __ __ __ __

Set 7: 1, 6, 2, 5 __ __ __ __

Set 8: 4, 1, 6, 8 __ __ __ __

Set 9: 2, 4, 1, 6 __ __ __ __

Set 10: 3, 6, 1, 5 __ __ __ __

5 Digit List: Auditory

Set 1: 3, 5, 1, 4, 6 __ __ __ __ __

Set 2: 8, 3, 6, 4, 2 __ __ __ __ __

Set 3: 1, 5, 2, 9, 6 __ __ __ __ __

Set 4: 3, 8, 6, 1, 9 __ __ __ __ __

Set 5: 1, 8, 4, 9, 2 __ __ __ __ __

Set 6: 8, 4, 6, 2, 5 __ __ __ __ __

Set 7: 4, 1, 3, 8, 6 __ __ __ __ __

Set 8: 3, 6, 8, 5, 1 __ __ __ __ __

Set 9: 1, 6, 8, 3, 9 __ __ __ __ __

Set 10: 9, 3, 6, 1, 5 __ __ __ __ __

5 Digit List: Auditory plus Noise

Set 1: 4, 2, 5, 9, 6 __ __ __ __ __

Set 2: 4, 9, 6, 1, 5 __ __ __ __ __

Set 3: 9, 5, 8, 6, 1 __ __ __ __ __

Set 4: 1, 6, 9, 3, 5 __ __ __ __ __

Set 5: 4, 1, 5, 9, 6, __ __ __ __ __

Set 6: 1, 8, 2, 6, 4 __ __ __ __ __

Set 7: 6, 4, 1, 5, 3 __ __ __ __ __

Set 8: 8, 2, 9, 3, 5 __ __ __ __ __

Set 9: 1, 9, 6, 2, 4 __ __ __ __ __

Set 10: 2, 8, 3, 9, 1 __ __ __ __ __

5 Digit List: Visual

Set 1: 8, 6, 9, 2, 4 __ __ __ __ __

Set 2: 8, 3, 2, 9, 5 __ __ __ __ __

Set 3: 6, 1, 4, 2, 5 __ __ __ __ __

Set 4: 6, 1, 8, 5, 2 __ __ __ __ __

Set 5: 2, 6, 1, 3, 9 __ __ __ __ __

Set 6: 2, 5, 8, 1, 6 __ __ __ __ __

Set 7: 3, 5, 9, 1, 6 __ __ __ __ __

Set 8: 4, 8, 1, 9, 3 __ __ __ __ __

Set 9: 4, 6, 8, 5, 1 __ __ __ __ __

Set 10: 2, 5, 8, 3, 6 __ __ __ __ __

6 Digit List: Auditory

Set 1: 8, 4, 2, 6, 9, 5 __ __ __ __ __ __

Set 2: 2, 8, 3, 1, 9, 6 __ __ __ __ __ __

Set 3: 3, 9, 4, 8, 6, 1 __ __ __ __ __ __

Set 4: 9, 4, 2, 5, 1, 6 __ __ __ __ __ __

Set 5: 3, 6, 8, 4, 2, 5 __ __ __ __ __ __

Set 6: 2, 8, 6, 5, 1, 3 __ __ __ __ __ __

Set 7: 6, 1, 3, 5, 4, 8 __ __ __ __ __ __

Set 8: 9, 3, 6, 4, 8, 2 __ __ __ __ __ __

Set 9: 3, 5, 2, 9, 1, 4 __ __ __ __ __ __

Set 10: 6, 8, 5, 2, 9, 4 __ __ __ __ __ __

6 Digit List: Auditory plus Noise

Set 1: 9, 1, 6, 8, 5, 3 __ __ __ __ __ __

Set 2: 3, 5, 9, 6, 1, 8 __ __ __ __ __ __

Set 3: 6, 4, 8, 2, 5, 3 __ __ __ __ __ __

Set 4: 3, 1, 4, 6, 2, 5 __ __ __ __ __ __

Set 5: 6, 9, 1, 4, 2, 8 __ __ __ __ __ __

Set 6: 6, 2, 8, 4, 1, 3 __ __ __ __ __ __

Set 7: 1, 9, 5, 2, 8, 3 __ __ __ __ __ __

Set 8: 2, 9, 4, 8, 5, 3 __ __ __ __ __ __

Set 9: 1, 8, 2, 5, 9, 3 __ __ __ __ __ __

Set 10: 9, 2, 6, 1, 5, 3 __ __ __ __ __ __

6 Digit List: Visual

Set 1: 4, 2, 8, 6, 9, 3 __ __ __ __ __ __

Set 2: 9, 5, 8, 1, 6, 2 __ __ __ __ __ __

Set 3: 4, 9, 6, 3, 8, 2 __ __ __ __ __ __

Set 4: 2, 6, 1, 5, 3, 9 __ __ __ __ __ __

Set 5: 1, 5, 9, 2, 8, 4 __ __ __ __ __ __

Set 6: 9, 2, 4, 1, 8, 5 __ __ __ __ __ __

Set 7: 4, 6, 9, 5, 8, 1 __ __ __ __ __ __

Set 8: 8, 4, 9, 3, 6, 1 __ __ __ __ __ __

Set 9: 5, 3, 9, 6, 2, 8 __ __ __ __ __ __

Set 10: 5, 8, 2, 3, 6, 1 __ __ __ __ __ __