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Phonological and Syntactic Processing, and the Role of Working Memory in Reading Comprehension Among High School Students

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A report submitted in partial fulfilment of the requirements for the award of Bachelor of Arts (Psychology) Honours, Faculty of Community Studies, Education and Social Science, Edith Cowan University.

October 2003

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Abstract

The performance of 60 year-8 students was examined on tasks measuring phonological processing, syntactic processing, and reading comprehension. The students were also administered several measures of working memory relating to the phonological loop and the central executive. A series of hierarchical regression analyses indicated that phonological processing and syntactic processing were both predictors of reading comprehension, and that the presence or absence of the latter distinguished good and poor comprehenders respectively. The phonological loop was found to play a small but significant role in the processes involved in reading comprehension, but not the central executive. Gender differences suggested that boys use relatively more phonological processing and girls relatively more syntactical processing to achieve similar levels of reading competency. Good reading comprehension appears to rely on basal levels of both phonological and syntactic processing. The results support the argument that these two processes complement one another, function concurrently, and act to reduce the demand on working memory.

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Supervisor: Professor Alison F. Garton
Submitted: October 2003

Declaration

I certify that this thesis does not incorporate, without acknowledgement, any material previously submitted for a degree or diploma in any institution of higher education and that, to the best of my knowledge and belief, it does not contain any material previously published or written by another person except where reference is made in the text.

Signature:

Date: 12/12/03

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Table of Contents

		Page
Title		1
Abstract		2
Declaration		3
Acknowledgement		4
Table of Contents		5
Introduction and Literature Review		6
Method		24
	Participants	24
	Reading comprehension measurement	24
	Phonological processing measurement	25
	Syntactic processing measurement	25
	Working memory measurement	27
	Procedure	30
Results		31
Discussion		42
References		52
Appendix A:	Introductory Letter to College Principal	57
	Introductory Letter to Parent/Guardian	59
	Parent/ Guardian Consent Form	60
	Student Consent Form	61
Appendix B:	Data disc	62
Appendix C	Test Instruments	63
	Working Memory Test Battery – Record Form	
	Woodcock Reading Mastery Test – Record Form	
	TORCH Test Booklet B	
	TORCH Answer Sheet	
	Syntactic Processing Test Stimulus Books	
	Syntactic Processing Test Questions	

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It is arguable that the most important skill a child acquires and requires in the educational process is the capacity to read. In recent times there has been considerable public and political debate about standards of literacy in our schools. This is an area of concern not only in Australia. The United Kingdom government has introduced measures in recent years to improve standards of literacy in British schools. Indeed, the introduction of routine standardised testing to evaluate the efforts of Western Australian schools to produce literate students mirrors similar steps taken in the United Kingdom. A concern with falling standards of literacy has tended to focus on the failure of educational programmes to teach our children to read, but an equally important aspect of the literacy debate lies in the fact that beyond learning to read, our children need to read to learn, which is specifically the case during secondary education.

This emphasis on learning to read has resulted in considerable research over recent decades aimed at the identification of the factors involved in reading disability, and consequently has tended to focus on children's reading ability in the early school years. An implicit assumption of the research is that the acquisition of reading skills is a progressive ability. Yet such an assumption may not be justified. A recent study has presented evidence that learning to read is not necessarily a linear process (Leach, Scarborough, & Rescorla, 2003).

The compulsory years of secondary education are particularly demanding of a student's ability to read to learn, and educational programmes

assume the child already has the ability to read. More specifically, it is assumed that the child who arrives at secondary school already has the necessary decoding skills involved in reading. Little attention is given to the possibilities that not only might the child fail to have acquired this skill, but even if the child has the decoding skills, might still not be capable of an appropriate level of comprehension (Nation, 1999). This study is concerned with exploring the skills demonstrated by secondary level students in the process of reading comprehension. It is postulated that phonological awareness, syntactic awareness and verbal working memory are necessary skills for reading comprehension.

As stated above, much of the research into reading processes has been concerned with identifying the skills involved in learning to read. A consistent conclusion of much of this research is that the single most effective predictor of reading ability lies in the child's phonological awareness (Blachman, 2000; Bowey, 2000; Goswami, 2000; Vellutino & Scanlon, 1987; Wagner, Torgeson, & Rashotte, 1994). Phonological awareness is concerned with the development of correspondences between the sound segments contained in speech and the visual segments of an alphabetic orthography.

The progression from oral language to reading acquisition is commonly thought to proceed through a number of stages. These stages comprise logographic coding, alphabetic coding and orthographic coding (Byrne, 1992). One way in which oral language can be coded in written form is by having a single visual symbol for each word in the language, as is the case with Chinese. This is how a logographic system operates. There is no use made of the internal structure of the word. It has been argued that a logographic system of

written language places excessive demands on the storage component of working memory and is consequently not as efficient as orthographic or alphabetic coding systems (Jones & Aoki, 1988). Both of the latter employ the internal structure of the word to generate a coding system which is less demanding of memory.

The English language employs an alphabetic system that facilitates awareness and utilisation of the internal structure of words. The smallest units of sound in spoken words are referred to as phonemes, and they are matched to letters or specific combinations of letters referred to as graphemes. There are about 45 phonemes in the English language from which every word in the English language is composed (Wagner, Torgesen, & Rashotte, 1994). Consequently, if all written language can be encoded using a recoding process based on this correspondence between graphemes and phonemes, then the storage demand can be reduced considerably from a logographic system. Orthographic coding contributes to greater efficiency by matching groups of letters and morphemic units.

Phonological awareness refers to the capacity to effectively employ this correspondence between the sound structure of oral language and the alphabetic orthography of written language. There are several stages to the acquisition of phonological awareness beginning with the ability to distinguish syllables within words, followed by a grasp of onset and rhythm which subdivides the syllable into the consonant sound preceding the vowel and the vowel sound itself, and finally, the eventual identification of individual phonemes within words (Goswami, 2000). Developmental and individual

differences in phonological awareness are believed to be causally related to reading ability (Stanovich, 1992).

In the foregoing comparison of the relative merits of logographic and alphabetic reading systems there has been a focus on the respective demands made of memory capacity. The implicit argument is that the more efficiently a written language can be coded, the less will be the demand on memory capacity resulting in speedier and more efficient processing. What is common to both coding systems is an active role for working memory in the reading process (Mann, 1985). What ought to be noted at this point is that references to "working memory" will be intended to embrace "short-term memory", and be distinguished on the basis that short-term memory refers exclusively to the phonological loop as suggested by Swanson and Ashbaker (2000). The relationship between working memory and reading competence is supported by empirical research (Swanson & Ashbaker, 2000; Swanson & Howell, 2001). Share, Jorm, MacLean and Matthews (1984) followed a group of students from kindergarten to the end of their first year of primary education and found a significant, although not large, relationship between working memory and reading performance. Swanson and Howell (2001) more recently conducted a study confirming the effects of working memory on reading performance of 9-year-olds and 14-year-olds.

However, in her review of the literature on the role of working memory in reading disability, Brady (1991) defined the working memory component of reading as an aspect of phonological ability and begged the question as to the distinction between working memory and phonological ability. Some studies have argued that phonological awareness and working memory are distinct

(Waters & Caplan, 2001) and others that working memory and phonological awareness share some common underlying factor (Macdonald & Christiansen, 2002). Hansen and Bowie (1994) presented evidence of both conditions. In a cross sectional study of young primary school students they measured reading achievement with sub-tests of the Woodcock Reading Mastery Test, phonological awareness using phonological oddity tasks, and working memory with tasks involving non-word repetition, sentence imitation, and rehearsal rate. The results indicated that phonological awareness and verbal working memory accounted for significant amounts of unique variance, but there was also a significant amount of common variance.

In an earlier effort to clarify the relationship between reading comprehension and working memory, Daneman and Carpenter (1980) criticised traditional measures of short-term memory such as digit span and word span on the basis that there are two different aspects of short-term memory involved in reading comprehension. The need for a storage and retrieval facility has already been referred to, but there is also a need for a degree of processing of stored information. It is self evident that reading comprehension requires a degree of reflection and correction as text becomes more complex, and consequently demands on processing become greater. In particular, the assignment of syntactic structure requires temporary storage whilst processing is going on (Waters & Caplan, 2001).

In a study that examined the ability of upper primary school children to comprehend sentences with restrictive relative clauses, Booth, MacWhinney and Harasaki (2000) found that good comprehenders showed a different pattern of accuracy scores from poor comprehenders. The latter were more likely to

make errors by associating the verb with the nearest noun when this was inappropriate, referred to as local attachment strategy, and a large memory span predicted the use of this strategy. Daneman and Carpenter (1980) point out that comprehension requires storage of information other than phonological, e.g., syntactical, and that such information may require to be available for understanding subsequent text, and may be an output of comprehension itself, implying some processing of the information. The results of Booth et al's. (2000) study suggest that a good memory span by itself may be necessary but not sufficient for the purposes of reading comprehension.

Daneman and Carpenter (1980) adopted a multi-component model of working memory first presented by Baddeley and Hitch (1974). The latter model comprised a central executive which carries out general processing requirements, and two slave systems, one of which, the phonological loop, functions as a short-term store of verbal material coded phonologically. Daneman and Carpenter (1980) developed the Reading Span test to combine heavy storage and processing demands simultaneously. This test required the participant to respond to increasing numbers of sentences and subsequently to recall the last words of each of the sentences, provoking a trade off between storage and processing. The test results correlated with the reading comprehension scores of college students. It seems that reading comprehension requires more than a phonological coding system and a competent short-term memory; it also requires processing capacity.

Daneman and Carpenter (1980) and Booth et al. (2000) alert us to the fact that the reader must be concerned not only with phonological data. Effective reading comprehension is not simply a matter of decoding and word

comprehension, it also requires the reader to process the structure of the text in addition to the internal structure of the words. The capacity to reflect on and manipulate the grammatical structure of sentences is known as syntactic awareness and has been shown to be related to reading ability (Tunmer & Hoover, 1992). In a study of brain damaged patients with language disorders, Martin and Romani (1994) concluded that there are separate components of working memory for the retention of phonological, semantic and syntactic information.

Tunmer and Hoover (1992) identified two ways in which syntactic awareness might influence reading development. Given its focus on the structure of sentences, syntactic awareness might facilitate monitoring of the ongoing comprehension in the manner referred to above. Here it appears to be performing an executive function in the manner described by Daneman and Carpenter (1980). The other way that Tunmer and Hoover (1992) suggested that syntactic awareness might influence reading is by helping children acquire phonological recoding skill. The argument here was that syntactic awareness implies a degree of language prediction – that is a top-down process that derives meaning from context. Consequently, Tunmer and Hoover (1992) concluded that reading comprehension requires a combination of phonological and syntactical processing. A corollary to the latter position is the absence of phonological ability will negatively affect decoding and consequently that reading comprehension will suffer as attention will be diverted from top-down processing (Bowey, 2000). However, this is not a universally held view.

Gottardo, Stanovich and Siegel (1996) conducted a cross-sectional study to examine the relationships between phonological sensitivity, syntactic

processing and verbal working memory in the reading performance of 8-year-olds. They challenged the evidence provided by Tunmer and Hoover (1992) that syntactic awareness can account for independent variance in decoding in addition to phonological awareness.

Gottardo et al. (1996) favour the phonological processing limitation hypothesis, a "bottleneck" model which regards reading as a unidirectional, bottom-up process, which commences with phonological processing before any syntactic processing occurs, and that the latter is dependent on competent phonological skills. In this model, sentences which increase the demands on working memory will reduce the comprehension levels of poorer readers, since working memory is required in the process of moving linguistic information upwards through the reading process. However, this reliance on working memory would only become more critical with decreasing levels of phonological skills. The model builds on Daneman and Carpenter's (1980) model of a trade off between storage and processing, whereby a shift from lower order phonological processing to higher order syntactic processing involves sufficient storage demand being freed up to accommodate the processing requirements at the syntactic level. Nevertheless, Gottardo et al. (1996) have an "each-way" bet by indicating that predictions will vary according to the complexity of the text employed as a criterion measure. Their explanation of the role played by working memory allows for increased reliance on the latter, and consequently on syntactic processing, as the complexity of the text becomes more complex, suggesting that the processes involved in reading comprehension may be as much a function of the text in question as the independent predictors of ability.

Such models of reading comprehension support the notion of independent processing and verbal storage modules within working memory. An alternative is to view working memory as a simple capacity constraint whereby if an individual has a small working memory capacity for language then phonological information may not be preserved during syntactic processing (Just & Carpenter, 1992). Just and Carpenter's (1992) theory of capacity constraint is based on the belief that differences between individual reading performances reflect differences in the maximum amount of activation available to support either storage or processing. When an individual faces high task demands, processing slows down and results in some memory loss, and when capacity is exceeded both storage and processing deteriorate, affecting both phonological and syntactic processing. The theory implies that storage and processing are carried out simultaneously and that working memory is a unitary concept. The capacity constraints can have the effect of generating apparent boundaries between storage and processing at the point where so much capacity is taken up that interaction between the two processes ceases.

This single resource theory of working memory is disputed by Waters and Caplan (2001) who used a variant of Daneman and Carpenter's (1980) Reading Span Test to collect data from a sample of young participants and patients with neurological disease. They predicted that syntactic processing relies on a specialised working memory system. They argued that performance on general verbal working memory tasks would not predict language processing efficiency, whereas the Reading Span Test would not only provide a working memory test, but also test the level of efficiency in the sentence

processing component of the test. They found a relationship between the results of the Reading Span Test and reading comprehension scores, and offered the explanation that both tasks involve structuring of sentences and assigning meanings whilst holding information in short-term memory. However, the correlation was a moderate one and the authors acknowledged that it did not offer a full explanation of sentence comprehension.

Several of the studies we have considered so far, despite their differences, would seem to support the perception that working memory is quite distinct from reading comprehension (Daneman & Carpenter, 1980; Just & Carpenter, 1992; Waters & Caplan, 2001). MacDonald and Christiansen (2002) argued to the contrary that such a distinction is artificial and a consequence of the measurement devices used by the various researchers. They challenged the idea of an architectural or modular explanation of reading comprehension and proposed that individual differences in reading comprehension skill ought to be attributed to variations in exposure to language and biological differences that might affect processing accuracy, e.g., differences in precision of phonological perceptions.

MacDonald and Christiansen (2002) raised an important area of concern around the validity of the operationalisation of the key constructs, viz., phonological awareness, syntactical awareness, and working memory. It is evident in the literature that different researchers generate slightly different definitions and these appear to be based on a degree of expediency and a desire to emulate the work of researchers who were primarily concerned with discovering factors involved in reading disability among children still learning to read.

Given that the focus of so much of the reading research has been on early emerging difficulties, it is important to consider the nature of the reading instruction that these young children typically experience. Leach, Scarborough and Rescorla (2003) suggested that early reading tuition is characterised by an emphasis on phonological principles and decoding. It would not therefore be surprising that phonological awareness would present itself as a notable predictor of reading ability. However, Leach, Scarborough and Rescorla (2003) referred to a phenomenon whereby some children around the fourth year of primary education show a marked deterioration in their reading ability at the stage when more complex texts demand higher order skills such as syntactic ability for the purposes of comprehension as opposed to simple decoding. It is therefore postulated that some late emerging reading difficulties might be a consequence of weakness in higher order skills necessary for comprehension, regardless of the level of phonological competency (Nation, 1999). In a study of children in their fourth year of primary education, Leach et al. (2003) found that late identified reading disability embraced a heterogeneous group of children including some with lower level deficits as predicted by research asserting that phonological awareness is the best predictor of reading ability, and others where the problem was not simply late identified, but late emerging and relating to higher order comprehension skills such as syntactic processing.

Whilst Leach et al. (2003) recommended caution in interpreting their results, it is a good basis for considering the possibility that the relative contribution of phonological and syntactical skills might be different for high school students compared to early primary students. The role of working

memory will depend on the balance of skills regardless of whether a multi component or unitary model of working memory is adopted. Assuming an architectural model of reading comprehension is valid, what sort of model of reading would be appropriate for the secondary school student?

One way of distinguishing possible models of reading comprehension is whether phonological and syntactic processing are carried out consecutively or concurrently. The processing limitation hypothesis is the most obvious example of the former (Gottardo et al., 1996) which explains individual differences in reading comprehension on the basis of differences in phonological processing capabilities. An alternative theory which combines consecutive development with a degree of parallel processing is the structural lag hypothesis. This postulates that phonological processing precedes syntactic processing, and that individual differences in reading comprehension are related to the degree of lag between phonological processing ability and the emergence of syntactic processing skill (Sheldon, 1974). In this model, the question whether processing is consecutive or concurrent will depend on the extent to which the individual has acquired syntactical skills. The cognitive-developmental model of metalinguistic development and reading acquisition proposes that both phonological and syntactic awareness develop and act in parallel to influence reading comprehension (Tunmer & Hoover, 1992). However, the relationship between phonological awareness and syntactical awareness on the one hand, and reading comprehension on the other, is mediated by phonological recoding and listening comprehension creating some confusion over definitions.

The second area to be explored in developing a model of reading comprehension relates to the role of working memory. The initial question is whether verbal working memory is independent of other linguistic processes. Indeed, it is possible that both positions have some validity. Recall that Hansen and Bowie (1994) established evidence to support such a possibility. The other question assuming that working memory plays an independent role in reading comprehension, is whether it represents a unitary factor as proposed by Just and Carpenter (1996) or a multi component resource as argued by Waters and Caplan (2000) and Daneman and Carpenter (1980).

One of the problems that has been raised in the literature is the fact that the key concepts, viz., phonological awareness, syntactical awareness, and working memory, are not defined and operationalised consistently across the literature. In one article alone, five different aspects of phonological processing are identified: phonological analysis, phonological synthesis, phonological coding in working memory, isolated naming and serial naming (Wagner, Torgesen, & Rashotte, 1994). To complicate matters further, Wagner et al. (1994) provide evidence that each of these aspects is characterised by different rates of development that result in corresponding individual differences. The phonological aspect is variously referred to as phonological awareness, phonological sensitivity, phonological skill, or phonological recoding. The most common distinction is between phonological awareness and phonological processing abilities (Windfuhr & Snowling, 2000). The distinction being made here is between the metalinguistic awareness of the internal phonological structure of words in the case of awareness, and the linguistic application of this knowledge in the case of

processing abilities. Given that phonological awareness must be a necessary if not sufficient condition of phonological processing, then any test demonstrating the latter will be an indication of the existence of the former. Whereas any study of the processes involved in learning to read would require the identification of phonological awareness in the absence of its application, this is not necessarily a requirement in the case of a study aimed at the processes involved in reading to learn.

Restricting any observations to phonological processing abilities does not resolve the need to distinguish phonological processing from working memory. It has already been suggested that an important advantage of a phonological system as opposed to a logographic one lies in the efficiency of phonological recoding in reducing the demands on working memory. At what point does phonological processing end and working memory begin or vice versa? One way that this might be accomplished is by distinguishing the process of recoding from the storage and processing of the results of recoding. Use of appropriate measurement tasks of phonological recoding and verbal working memory ought to assist in this matter. Recoding must precede memory in the first instance insofar as we must have 'information in' before 'information out'. Assuming that phonological processing embraces both recoding and working memory, empirical evidence of recoding ought to be reflected in measurements of verbal working memory. The latter will be more clearly demonstrated if Baddeley and Hitch's (1974) model distinguishing the processing and storage components of working memory is assumed. It should then be possible to distinguish, phonological recoding, storage, and processing.

It is widely accepted that reading comprehension involves both a bottom-up process based on deriving meaning from context, and a top-down process constructing meaning from the smallest meaningful units of text. The former is generally associated with phonological processing and the latter with syntactic processing . Nevertheless it has been argued that syntactic processing depends on phonological processing to the extent that the former fails to predict reading ability when results are controlled for phonological awareness (Gottardo, Stanovich, & Siegel, 1996). However, it has equally been demonstrated that despite phonological competency some individuals have difficulty in reading comprehension in a condition known as hyperlexia (Nation, 1999). The present study will therefore seek evidence that both phonological and syntactic competences are features of good reading comprehension.

Given the earlier acknowledgment that the child learning to read will receive formal instruction in phonological skills prior to any emphasis on syntactic skill, and given the predominant research results supporting the primary role of phonological skills in learning to read, it is anticipated that phonological processing will give way to syntactic processing for the purposes of comprehension. It has been argued that syntactic structures are already in place for the youngest reader as they are developed in the process of learning oral language (Shankweiler, 1989). However, it is assumed that the employment of syntactic processing depends on the demands of the text and that a young reader is unlikely to be confronted with a text requiring the application of this skill. Consequently it seems irrelevant when the child developed the ability as our interest here lies in how and when it is applied.

The capacity constraint theory of working memory proposes that the processing demands of higher order processing such as syntactic processing are limited by the predominantly storage requirements of lower order phonological processing.

Swanson and Ashbaker (2000) conducted a study of school children with varying degrees of reading difficulty to discover whether their reading deficits ought to be exclusively attributed to the phonological loop or alternatively that the central executive played an independent role. They concluded that the latter was the case. This seems surprising given that the participants were selected on the basis of their reading deficits. It also limits the generalisability of their results for present purposes. However, the study was followed up with another study, referred to previously, where the researchers compared a group of 9-year-olds and 14-year-olds, all of whom were assessed as having average scholastic ability. They produced evidence that age related improvements in reading performance were due to the central executive rather than the phonological loop (Swanson & Howell, 2001). If it is assumed that syntactic skill is a higher order process that develops after phonological skills then it could be anticipated that a test of the phonological loop will more likely reflect phonological processing whilst a test of central executive working memory will more likely reflect the intrusion of syntactic processing.

This discussion has raised a number of questions in relation to the skills involved in reading comprehension of experienced readers. There has been a long running debate as to whether phonological and syntactic skills make unique contributions to reading comprehension. Whilst the research involving

young children in the process of learning to read has tended to favour the former at the expense of the latter, more recent research suggests that the developmental stage of the student may be a factor and opens up the possibility that syntactic processing may indeed be influential for reading comprehension performance as the older student is confronted with more demanding texts. It is hypothesised in this study that both phonological and syntactic processing make unique contributions to reading comprehension.

Following on from this is the question as to the relative roles of phonological and syntactic processing. Although some research favours the parallel development of both skills, it is hard to disregard the role that reading experience has, and consequently that until the child develops sufficient decoding skills is unlikely to experience the standard of text to demand much higher order processing. Consequently, this study hypothesises that the relative contributions of phonological and syntactic skill will vary inversely with the competency of the reader, and thus the influence of syntactic skill ought to be more in evidence in the case of a child demonstrating greater competence in reading comprehension.

As it is intended to adopt measurement techniques that assess the application of phonological and syntactic skill as opposed to any metacognitive or metalinguistic quality, a clear distinction is expected to be in evidence between working memory and the other two skills. It is expected that phonological and syntactic skills will each depend on effective working memory.

Finally, in the event that the last expectation is confirmed, this study will address the question of whether working memory is unitary or has multiple

components. It is anticipated that the phonological loop will be a necessary and sufficient condition of phonological recoding, whereas the effective functioning of the central executive will be necessary for syntactic processing. In the event that working memory is a unitary process, then the data in respect of the two aspects of working memory will not discriminate between the two skill areas.

This study thus addresses the following hypotheses:

(i) that both phonological and syntactic processing make unique contributions to reading comprehension ability among high school students;

(ii) that the relative contributions of phonological and syntactic skill vary inversely with the level of competency of the reader, the former being more pronounced in the case of lower ability students and the latter more pronounced in the case of higher ability students;

(iii) that both phonological and syntactic processing will depend on effective working memory;

(iv) that phonological and syntactic processing will each depend on a different component of working memory: specifically, that phonological processing will depend on the phonological loop, and syntactic processing will depend on the central executive.

Method

Participants

The study involved 60 year- 8 students. The participants all attended the same secondary school in suburban Perth. Selection from the year- 8 cohort was carried out by randomly selecting two houses. All 66 students from these two houses were invited to participate. This initial stage of recruitment produced 35 girls, but only 16 boys. The poor response from male students reflected boys' general reluctance to participate in extra curricular activities other than sport. Subsequently, a third house was randomly selected from the remaining four houses and only the boys invited to participate. This produced a further nine boys, bringing the total number of male participants to 25 along with 35 females. All the participants celebrated their 13th birthday during the year in which the study was conducted.

Design and Materials

Reading Comprehension Skill. The Tests of Reading Comprehension (TORCH) were developed by the staff of the Curriculum and Research Branch of the Western Australian Education Department in 1982, and are used extensively in Western Australian schools. This is a group administered, untimed, cloze type test. TORCH contains 14 graded passages. One of these passages, 'Iceberg Towing', was selected for the purpose of this study to measure the reading comprehension skills of the participants. The participants are required to read the passage of text and a retelling of the same passage that contains gaps, which can be completed from details in the original text using the participant's own words. The test provides a measure of comprehension on a Rasch type scale that ranges from zero to 100. TORCH has good reported

reliability (KR = .92) (Mossenson, Hill & Masters, 1987). The Rasch type calibration also testifies to the reliability of the instrument. The test authors argue that no statistical procedure satisfactorily accounts for validity (Mossenson, Hill & Masters, 1987) but describe qualitative measures taken to support the content validity of TORCH.

Phonological Recoding Skill. It was considered that the ability to pronounce unfamiliar words or non words would demonstrate the capacity of the participant to apply phonological principles since it requires the correct matching of visual letter arrangements with corresponding phonemes (Bowey, 2000). The Word Attack sub-test from the Woodcock Reading Mastery Tests-Revised (Form G + H) (Woodcock, 1998) was ideal for the purpose. The test consists of 45 nonsense words that comprehensively cover the range of phonemes in the English language. The test measures the participant's competence in the application of phonics and structural analysis of the internal structure of words. One mark is assigned for each correct answer to give a final score out of 45. The Word Attack test has good reported reliability (r = .95, SEM = 3.2) and documented concurrent validity for this age group of participants (Woodcock, 1998). Test scores correlate well with the Woodcock Johnson Reading Tests (r = .85), with the respective Word Attack tests having a lower, but adequate correlation for year 8 students (r = .64).

Syntactic Processing Skill. The aural moving-window technique has been used extensively to measure syntactic processing skill (Ferreira, Henderson, Anes, Weeks, & McFarlane, 1996). Participants process what Ferreira et al. (1996) refer to as 'garden path' sentences which contain a temporary ambiguity due to a degree of syntactic complexity. The participant

has control of the rate at which each word in the sentence is presented and is required to process the sentence on-line, either aurally or visually. Measurements are taken of responses such as eye movement and processing time. This is followed by a measure of off-line processing involving responses to questions that assess whether syntactic ambiguities have been resolved correctly.

Whereas Ferreira et al., (1996) used the technique to assess spoken language, Booth et al. (2000) used the visual moving-window technique to assess the ability of the participant to process printed sentences containing varying types of syntactic ambiguity in the form of restrictive relative clauses. Each participant was presented with three types of sentence. Subject-subject (SS) sentences such as "The boy that sees the girl chases the policeman" involve the head noun as the subject of both clauses. Subject-object sentences, such as "The boy that the girl sees chases the policeman", involve the head noun as the subject of the main clause and the object in the relative clause. The third type of sentence involved a conjoined verb phrase (CVP) such as "The pilot bribed the clown and flew the kite in the air", in which the analogous parts of the sentence contain a verb and the conjunction "and". Each sentence was followed by a single question requiring a true or false answer to establish whether the syntactic structure had been interpreted correctly.

This study uses a test that approximates that of Booth et al. (2000) described above. In the absence of available computer technology, the sentences were printed on cards to appear as they would have looked on screen. As a consequence the sentences were presented phrase-by-phrase rather than

word-by-word. The sentences were printed in Times New Roman using a 26 font, on cards which were 150mm x 100mm in size. The cards were made up into three ring books, one for each type of sentence. Participants read each sentence by flipping over the pages as if changing screens. There were eight sentences contained in each book, and participants read a sentence from each book in turn until each had responded to all 24 sentences.

Each sentence was followed by a question demanding a true or false response. There were four possible permutations for each question, all of which required the participant to determine the subject of either the first or second verb. Two lists of questions were compiled and used alternatively, and each contained a mix of all question types. Scores were based on the number of correct off-line responses giving a score out of 24.

Working Memory. Gathercole and Pickering (2000) used cognitive methods to develop a test battery for working memory that would measure the separate components of working memory originally proposed by Baddeley and Hitch (1974). The different tests incorporated into the battery were already well-established experimental techniques in the area of working memory research. The original battery was designed for use with 6- and 7-year olds. However, Pickering and Gathercole (2001) subsequently developed the test battery to accommodate children between 5 and 15 years of age. The battery consists of nine sub tests designed to tap the three principal components of working memory, viz., the central executive, the phonological loop, and the visuo-spatial sketchpad. This study utilises one of the tests of the central executive and two of the tests of the phonological loop.

The phonological loop is primarily concerned with storage of the phonological forms of new words (Baddeley, Gathercole, & Papagno, 1998; Gathercole & Pickering, 2000). Given that the focus of the phonological loop is on unfamiliar words, it should be particularly active in remembering non-words. Nonword stimuli are considered to produce a highly sensitive measure of phonological storage (Gathercole & Pickering, 2000). Additionally, given the constraints on the time available for testing, this test has the advantages that it is relatively simple and quick to administer, and uses non-lexical material thus producing results which cannot be confused by familiarity with the to-be-remembered material (Gathercole & Baddeley, 1989). This study consequently selected the Nonword List Recall test as one of two measures of the phonological loop. In this test the participant is required to repeat sequences of single syllable nonwords that have been read to them. The other test of the phonological loop selected for this study was the Word List Matching test that measures immediate memory for words using a matching-span paradigm. The participant is presented with pairs of word lists and asked to indicate whether the order of words in the second list is the same as in the first list. The latter test is expected to involve a degree of subvocal rehearsal whereas the former is a test of storage alone and does not involve rehearsal.

Of the three tests available in the battery for testing the central executive, the best choice was considered to be the Listening Recall test. This test is a modified version of the Reading Span test first developed by Daneman and Carpenter (1980) which has subsequently been used extensively in this field of research (Just & Carpenter, 1992; King & Just, 1991; Waters & Caplan, 2001). A listening version of this test produces similar results to the

reading version (Daneman & Carpenter, 1980). This test requires the participant to listen to sets of short sentences, some of which make sense while others do not. Following each sentence the participant indicates whether the sentence is sensible or not with a true/false response format. Following the complete set the participant must recall the last word of each sentence in the set in the correct order.

The test authors only report reliability coefficients for students in years 1 and 6. The respective Pearson product moment correlation coefficients for each subtest are: Word List Matching, 0.45 and 0.42; Nonword List Recall, 0.68 and 0.43; and Listening Recall, 0.83 and 0.38. Inter-tester reliability ranges from $r = .86$ to $r = .90$.

The internal validity of this multi component model of working memory is based on the research conducted by Gathercole and Pickering (2000) in respect of 6- and 7-year-olds and supported in the test manual (Pickering & Gathercole, 2001). The five tests of the phonological loop correlated significantly with one another, as did the central executive tests. These two components were identified by exploratory and confirmatory factor analysis, and ıd a covariance coefficient of 0.55. External validity was established by comparing the results with a range of standardised attainment test results. Correlations between the prototype measures and attainment test results for 8 year-old students indicated that phonological loop scores were most highly associated with vocabulary. The authors concluded that this evidence along with evidence from other sources is indicative of a strong link between the phonological loop and the ability to learn new vocabulary (Pickering & Gathercole, 2001). The same set of correlations indicates that

central executive tests correlate significantly with attainment test results across the board.

Procedure

All testing of the participants was conducted within the school with the consent of the parents and the participants. The conduct of the study had the approval of the school principal and ethics approval from the university.

The participants were administered the TORCH test in a group setting during a normal class period of approximately 50 minutes duration. The remaining tests were administered individually in a single session averaging about 40 minutes. The order in which the individual tests were administered was Word Attack, Nonword List Recall, Listening Recall, Syntactic Processing, and Word List Matching. Individual testing was conducted over the period of a 10-week term by the researcher. TORCH testing was conducted during the previous term by the respective classroom teachers.

Results

The analyses of data proceeded through six steps. First, a preliminary examination of the data looked at the means, standard deviations, and bivariate correlations. The data were screened for missing data, outliers, and normality of their distributions. Second, a standard multiple regression was conducted to establish the respective contributions of phonological and syntactic processing to reading comprehension. Third, the sample was split into those participants who scored below the mean on TORCH, and those who scored above the mean on TORCH ($M = 58$). An independent samples t-test was conducted to establish that this division of the sample resulted in two different samples. Hierarchical regression analyses with reading comprehension as the criterion variable were conducted with each sample with a view to establishing differences in the respective contributions of phonological and syntactic processing. Fourth, simple regression analyses were conducted to establish the extent to which working memory predicted phonological processing and syntactic processing respectively. Fifth, hierarchical regression analyses were conducted with phonological processing and syntactic processing as respective criterion variables to assess the relative contributions of the phonological loop and central executive to each of them. Finally, in view of current interest in the relative performance of boys and girls, steps were taken to identify any differences arising from gender.

Raw scores were used in the analyses for TORCH, Word Attack, and the Syntactic Test. Standard scores were employed for the three working memory tests, and the Working Memory scores consisted of the aggregate of the latter three scores.

Preliminary Examination of Data

Descriptive statistics for all measures are reported in Table 1. There were no missing data. Boxplot examination indicated a couple of outliers among the Word Attack results and none for any of the other variables. These latter scores were only marginally below the 25th percentile, and it was considered that excluding the outlying cases would cause greater distortion than if they were included. Mahalanobis distance scores confirmed that there were no multivariate outliers. Consequently, data for all 60 participants were included in the analyses.

In view of the relatively small sample, a visual examination of the normal probability plots and detrended normal plots for each variable was relied upon to assess normality. A negative skew was evident in the distribution of the Word Attack scores. A logarithmic transformation improved the distribution, however, subsequent re-analysis using the transformed variable did not alter the results and so the original data were retained. All the other variable distributions appeared normal.

Table 1

Means and Standard Deviations of Experimental Measures
(N = 60)'

Measures	Mean	SD	Max*
Torch	58	9.01	83
Word Attack	35.82	4.32	45
Syntactic Test	18.40	2.59	24
Non Word Recall	103.93	10.14	
Listening Recall	100.22	16.86	
Word List Matching	95.03	13.14	

*indicates the maximum possible score where applicable

Correlations among the experimental measures can be seen in Table 2. The strongest relationships are between TORCH scores, and Word Attack and Syntactic Test scores respectively. This relationship was supported by multiple regression analysis reported below. Any relationships beween the three measures of working memory were quite small and consistent with the model informing the test battery. The only measure of working memory showing a relationship of any size was the Non Word List Recall test, which has a moderate relationship with TORCH.

Table 2

Simple Correlations Among Experimental Measures (N = 60)

	1. Torch	2. Syntac	3. W/Attack	4. Non Word	5. Listen	6. L/Match
1. Torch Test	1.00	.567**	.522**	.403**	.209	.245
2. Syntactic Test		1.00	.335**	.311*	.241	.259*
3. Word Attack			1.00	.302*	-.049	.111
4. Non word List Recall				1.00	.144	.270*
5. Listening Recall					1.00	.142
6. Word List Matching						1.00

** $p < .01$
* $p < .05$

Contributions of Phonological and Syntactic Processing to Reading Comprehension

In order to establish whether phonological processing and syntactical processing each contribute to reading comprehension a standard multiple regression using SPSS version 11.0 was conducted with reading comprehension as the dependent measure and phonological and syntactic processing as the independent variables. The reason for this choice of regression method is that it is the best method for assessing the relationship

between all the variables and it takes account of the unique contribution of each independent variable. Results of the analysis are presented in Table 3.

Table 3

Standard Multiple Regression Analysis Predicting Reading Comprehension from Phonological and Syntactic Processing Skills

Model	Standardised Coefficients Beta	t	Sig.
1. (constant)		.219	.827
Syntactic	.442	4.222	.000
Phonological	.374	3.573	.001

Both independent variables made a significant contribution to the prediction of reading comprehension ability, with syntactic processing making a marginally greater contribution than phonological processing ability. The model accounted for 44.6 % of the total variance ($R^2 = .446$) and was significant $\underline{F}$ (2, 57) = 22.9, $p < .05$. Examination of the residuals confirms the assumptions of linearity, homoscedasticity, and independence of the residuals. This result supports the first hypothesis that phonological processing skill and syntactic processing skill are both features of good reading comprehension.

The relative contributions of phonological processing and syntactic processing to different levels of reading comprehension skill.

The foregoing analysis considered the relative contributions of phonological and syntactic processing to reading comprehension generally. The next question relates to whether the relative effects of these two processes vary with the level of reading comprehension ability. For this purpose the sample was split into two on the basis of reading comprehension scores. One group consisted of those participants with a TORCH score of 57 or less (*n* =

28), and the other of participants with a TORCH score greater than 58 (n = 32). The cut-off point was selected on the basis that it split the original sample into two approximately equal groups either side of the mean (M = 58). An independent samples t-test was carried out which confirmed that the two groups were significantly different in respect of reading comprehension. The results of the t-test are presented in Table 4.

Table 4

T-test Results Confirming Difference Between Higher and Lower Ability Reading Comprehension Groups

	t	df	Sig. (2-tailed)
Equal variances assumed	-9.098	58	.000
Equal variances not assumed	-9.052	55.536	.000

It was hypothesised that the lower ability reading group would have greater dependence on phonological recoding than the higher ability reading group, and correspondingly, that the higher ability group would have more dependence on syntactic processing than the lower ability reading group. Hierarchical regression analysis was selected for the purpose of testing these hypotheses, as it provides for the independent variables to be entered into the regression equation according to the hypothesis being tested. Two analyses were conducted. In both instances reading comprehension was the dependent variable and phonological and syntactic processing were the independent variables. However, the order of entry of the independent variables changed for the two groups. In respect of the lower ability group, phonological processing was entered first, followed by syntactic processing. Entry was reversed in the case of the higher ability group. The results are presented in Table 5.

Table 5

Summaries of Hierarchical Regression Analyses Predicting the Relative Effects of Phonological Processing and Syntactic Processing on Reading Comprehension among Lower and Higher Ability Readers respectively.

	Lower Ability		Higher Ability	
	Increase In R^2	F	Increase In R^2	F
Steps 1 and 2:				
1. Word Attack	.148	4.516*	.011	.347
2. Syntactic Test	.073	2.331	.115	3.809
1. Syntactic Test	.102	2.947	.122	4.167*
2. Word Attack	.119	3.812	.004	.140

*$p < .05$

The lower ability group analysis indicates that phonological skill on its own contributes 14.8% of the variance in reading comprehension and is a significant predictor. When syntactic processing is added to the equation it only adds 7 % to the explained variance, and this increase is not significant. Moreover, when both independent variables are entered into the regression equation, phonological processing ceases to be a significant predictor of reading comprehension. This suggests a degree of collinearity between phonological and syntactic processing. However, the tolerance value of syntactic processing is acceptable (.982).

The higher ability group analysis indicates that syntactic processing accounts for 12.2 % of the variance in reading comprehension. When phonological processing is added it only increases the explained variance by an insignificant 0.4 %. As in the case of the lower ability group, when both independent variables are included in the equation the first variable, syntactic processing, loses its significance, suggesting a degree of collinearity. However, phonological processing has a relatively high tolerance (.985).

These results provide some support for the hypotheses that phonological processing skill is the best predictor of reading comprehension ability in a lower ability group, and that syntactic processing is the best predictor of reading comprehension ability in a higher ability group. However, the respective amounts of variance accounted for by each of the regression equations is quite small.

The relationship between working memory and phonological and syntactic processing.

It was further hypothesised that both phonological processing and syntactic processing each rely on working memory. Both processes were tested using simple regression analysis. The results are presented in Table 6. Working memory only accounted for 1.8 % of the variance in phonological processing and was not significant ($p > .05$). In contrast working memory accounted for 15.1 % of the variance in syntactic processing and this result was statistically significant ($p < .01$). These results suggest that working memory plays no role in phonological processing, but it has to be noted that the definition of phonological processing used in this study is restricted to phonological recoding. Although the results indicate that working memory helps to explain syntactical processing, it only accounts for a small proportion of the variance.

Table 6

Correlation between Working Memory Scores and Processing Variables Together with Percentage Variance Accounted for by Each Based on Simple Regression

Measure	Correlation Coefficient (R)	% Variance (R square)	Sig.
Phonological Processing	.136	.018	.300
Syntactic Processing	.389	.151	.002

The relative contributions of different components of working memory to phonological processing and syntactic processing respectively.

The latter analyses considered the relationship between the composite working memory scores and reading processes and found there only to be a significant relationship between working memory and syntactic processing. However, the working memory score is the sum of scores on three tests that reflect two different components of working memory, viz., the phonological loop and the central executive. It was hypothesised that each of these components would have differential effects on phonological and syntactic processing respectively. It was expected that phonological processing would have greater reliance on the phonological loop measured with the Nonword List Recall Test and the Word List Matching Test, and that syntactic processing would have greater reliance on the central executive measured with the Listening Recall Test.

These relationships were explored using hierarchical regression analyses. The first of these analyses explored the relationship between phonological processing and working memory. The order of entry of the

predictors was Nonword List Recall, Word List Matching, and Listening Recall as predicted in the hypothesis. The second analysis explored the relationship between syntactic processing and working memory. The order of entry reversed the order of working memory components, placing the central executive test first in accordance with the hypothesis, i.e., Listening Recall, Nonword List Recall, and Word List Matching. The results of both analyses are presented in Table 7.

Table 7

Summary of the Results of Hierarchical Regression Analyses Exploring the Relationships between the Components of Working Memory and Phonological Processing and Syntactic Processing respectively.

	Word Attack		Syntactic Test	
	Increase In R^2	F	Increase In R^2	F
Steps 1, 2, and 3:				
1. Nonword List Recall	.091	5.825*	.096	6.194*
2. Word List Matching	.001	.060	.033	2.173
3. Listening Recall	.009	.586	.032	2.148
1. Listening Recall	.002	.137	.058	3.569
2. Non Word List Recall	.098	6.179*	.078	5.127*
3. Word List matching	.002	.106	.026	1.745

*$p < .05$

The results support the prediction that phonological processing depends to some extent on the phonological loop as opposed to the central executive. However, the working memory component only accounts for 9.1 % of the variance in phonological processing scores. The prediction that syntactic processing would be more dependent on the central executive than the phonological loop was not supported. In fact the results indicate that syntactic processing is also dependent on the phonological loop which accounts for 9.6 % of the variance in syntactic processing scores.

The phonological loop was measured with two tests, the Nonword List Recall Test and the Word List Matching Test. However, any conclusions about the influence of the phonological loop above are premised solely on the Nonword List Recall scores. The Word List Matching scores failed to make a significant contribution in any of the foregoing analyses, and this is not due to correlation between the two sets of scores ($r = .27$). The implication is that each test measures something different and consequently that the phonological loop may itself contain more than one component.

The foregoing analyses suggest that whilst working memory may not directly contribute to reading comprehension, nevertheless, a component of phonological memory as measured by the Non Word List Recall Test makes a small but significant contribution to both phonological and syntactic processing. These latter two processes in turn influence competency in reading comprehension.

Gender differences in the relative contributions of phonological and syntactic processing to reading comprehension.

In view of topical concerns about levels of literacy among boys in particular, standard regression analyses were conducted to see whether the relative use of phonological and syntactic processing was the same for both boys and girls. The results require to be treated with caution in view of the small sample sizes ($n = 25$ boys and 35 girls). Results are outlined in Tables 8 and 9. The boys' model accounted for 67.6% of the total variance ($R^2 = .446$) and was significant, $F\ (2, 22) = 22.9$, $p<.05$. The girls' model accounted for 40.5% of the total variance ($R^2 = .405$) and was also significant, $F\ (2.32) = 10.9$, $p<.05$.

Table 8

Standard Multiple Regression Analysis Predicting Reading Comprehension from Phonological and Syntactic Processing Skills for Boys

Model	Standardised Coefficients Beta	t	Sig.
Word Attack	.607	4.731	.000
Syntactic Test	.390	3.038	.006

Table 9

Standard Multiple Regression Analysis Predicting Reading Comprehension from Phonological and Syntactic Processing Skills for Girls

Model	Standardised Coefficients Beta	t	Sig.
Syntactic Test	.544	3.669	.001
Word Attack	.179	1.205	.237

The most interesting aspect of these results is the indication that the influences of phonological processing and syntactic processing are reversed according to gender. Boys' reading comprehension is better predicted by their phonological processing skills and girls by their syntactic skills. This result cannot be attributed to differences in the reading comprehension levels of the two groups as their respective means and standard deviations are almost identical. It begs the question whether boys rely more on bottom-up reading processes and girls on top-down processes.

Discussion

The results of this study support the first hypothesis that both phonological and syntactic processing skills contribute to reading comprehension among teenage students. This result supports the cognitive-developmental model of metalinguistic development and reading acquisition of Tunmer and Hoover (1992) and stands in contrast to many studies of younger children who are still learning to read (Gottardo et al., 1996). These studies frequently conclude that phonological processing is the single dominant influence on reading ability. One of the main differences between the two age groups lies in the relative complexity of the texts they are required to process. The texts employed for teaching younger children how to read have a very simple syntactic structure. The primary purpose of the text is to encourage improvements in the decoding skills of the student. The student is consequently challenged by the internal structure of the words rather than the structure of the text. Older students on the other hand are frequently confronted in school with texts that have complex syntactic structures. The primary purpose of the text is to impart knowledge contained in the text as a whole. The student is consequently challenged by the structure of the text in addition to the decoding task. The latter is arguably much less demanding by this stage of the students education.

This raises the question as to whether the implied progression from the development of phonological processing skills to the development of syntactic processing skills is a function of cognitive development or a function of the text development, or is it a reciprocal process. The notion that the complexity of the text plays a role in the development of processing skills is very plausible

(Leach et al., 2002). Gottardo et al. (1996), despite excluding syntactic processing as a factor in reading comprehension, nevertheless predicted the possibility that the processes involved might reflect the difficulty of the text and consequently the possibility that syntactic processing might still play a significant role if the text demanded it. However, the difference in results between boys and girls invites caution about reaching such a conclusion. If we assume that the boys and girls have been exposed to the same texts as they progressed together through school, which seems a reasonable assumption, then we could expect both groups to have developed the same degree of syntactic processing ability. If this is so then why do girls appear to continue to make greater use of syntactic ability than boys? The other related question that needs to be raised is why, despite having less reliance on syntactic processing, the boys' reading comprehension ability is nevertheless as good as that of the girls? The implication is that different blends of cognitive processing can achieve the same sort of outcome in reading comprehension. Also, the combination of processing, whether in the case of boys or girls, still leaves a large proportion of the variance in comprehension scores unaccounted. Is there another as yet unidentified cognitive process involved in reading comprehension, which might explain the complex relationship between phonological and syntactic processing?

The second hypothesis postulated that the relative contributions of phonological and syntactic processing would vary according to the reading ability of the child, specifically, that the proportion of syntactic processing will increase as comprehension ability increases. Is it possible that although the gender differences discussed above suggest the possibility that different

combinations of phonological and syntactic processing can nevertheless achieve similar levels of reading comprehension skill, that within a mixed gender group particular combinations may be indicative of the level of competency in reading comprehension?

The results of the hierarchical regression analyses indicated that there is a significant difference in the relative use of phonological and syntactic processing between the lower and higher comprehension ability groups. The group of students who scored below the mean on the reading comprehension test demonstrated greater reliance on phonological processing, and in fact the contribution from syntactic processing was not significant. Exactly the converse was found in the case of students who scored above the mean on the reading comprehension test. This begs the question as to why the analysis controlling for gender suggests that the relative contributions of phonological and syntactic processing are not predictive of reading comprehension levels, whilst analyses controlling for comprehension levels suggests the contrary. Is there a difference between boys and the lower ability group, or between girls and the higher ability group?

One possible explanation, which would resolve this apparent contradiction, is that a basal level of phonological processing is a necessary condition of syntactic skill, and that a basal level of syntactic skill is necessary for good comprehension of texts with a certain level of structural complexity, and that capacity beyond these basal levels is unnecessary. That the former is a necessary requirement for reading comprehension and precedes syntactic processing is well documented in the literature. A comparison of the hierarchical regression results for lower ability readers with the hierarchical

regression results for boys shows that whilst both groups share the predictive power of phonological processing, the boys' regression equation includes syntactic processing whereas the regression equation for the lower ability group excludes a significant predictive role for syntactic processing. The implication is that regardless of the predictive power of the phonological component some significant contribution of the student's syntactic ability is necessary for above average comprehension.

The girls' comprehension skills can be predicted from their syntactic processing skill but their phonological skill does not improve the prediction, so does this contradict the need for a basal level of phonological processing? This result may be due in part to the difficulty in creating a measure of syntactic processing skill that does not incorporate some amount of phonological processing. The syntactic processing test used in this study requires the participant to decode the words in addition to organising the structural relationships in the sentences. Whilst it is possible to establish phonological skill in the absence of syntactic skill, the converse is difficult to achieve. Consequently it could be inferred that by achieving competency in reading comprehension through syntactic competence the student has an adequate level of phonological recoding skill to satisfy the proposed basal level requirement.

This explanation allows for variation in levels of each method of processing without affecting levels of competence in comprehension It also allows for the possibility that whilst phonological processing need not appear to make a significant contribution to the prediction of comprehension con.petency at higher levels of syntactic processing as appears to be the case with girls, that it in fact does so, but that it is concealed by limitations in the

operationalisation of the concepts. Some evidence that the phonological loop makes a significant contribution to both phonological and syntactic processing supports this position. This brings us to the part played by working memory in reading comprehension

The third hypothesis was concerned with the relationship between working memory and phonological and syntactic processing. It was anticipated that each type of processing would rely on working memory. However, the results indicated that only syntactic processing can be predicted on the basis of working memory, which accounted for 15.1% of the variance in reading comprehension scores. Working memory made no significant contribution to the prediction of phonological processing skill. This may be due in part to the care that was taken in operationalising phonological processing to ensure that it was independent of working memory. Given that phonological processing was reduced to the more restricted concept of phonological recoding, it can be argued that the latter does not require any significant level of working memory. This would not be true of syntactic processing which as a concept proved much harder to operationalise in a way that maintained its independence from other variables as has already been mentioned above. Consequently the results may be a reflection of the design.

The working memory scores used to explore the relationship with phonological and syntactic processing were an amalgam of scores representing two distinct memory functions. The fact that this composite score did not predict competency in phonological processing does not preclude the possibility that one of these functions might predict phonological processing skill. This was the fourth hypothesis, that the phonological processing relies on

the phonological loop, whilst syntactic processing depends on an effective central executive. It had been anticipated that phonological processing would be predicted by measures of the phonological loop and syntactic processing by a measure of the central executive. The results established the first part of the hypothesis, but not the second part. The phonological loop makes a small but significant contribution to both forms of processing. The central executive failed to contribute significantly to either process. The amount of variance accounted for in each case was almost identical. This again could be due to the operationalisation of the concepts. The operation of the phonological loop in syntactic processing may be a reflection of the phonological processing occurring within the syntactic processing test. The implication is that the only function served by working memory in the process of reading comprehension is the more traditional one of short-term storage required for the decoding process. If this is the case then it is understandable that previous studies had difficulties in distinguishing working memory from phonological awareness.

If the application of working memory is restricted in the manner described, then how can one explain the necessary storage of syntactic information when reflection is required? It seems clear that in the absence of evidence of central executive activity that syntactic information must either be stored in coded form in the same manner as phonological or semantic data, or alternatively that there is some other as yet unidentified process occurring. The former would support the view expressed by Tunmer and Hoover (1992) that syntactic processing might contribute to phonological recoding.

Insofar as the study results are consistent with the idea of a basal level of working memory focused on phonological data being sufficient for reading

comprehension, they are inconsistent with the phonological processing limitation hypothesis which assumes that the memory requirement in reading comprehension continues to increase with the complexity and demands of the text. Nor are the results consistent with Daneman and Carpenter's (1980) model of a trade off between storage and processing. There is no evidence from this study to support the notion of independent processing and verbal storage modules operating in reading comprehension. The evidence from this study is more consistent with MacDonald and Christiansen's (2002) theory that individual differences in reading comprehension are due to, among other things, biological differences such as phonological perceptions. The results are also consistent with Sheldon's (1974) structural lag hypothesis whereby phonological and syntactic skills are developed consecutively and individual differences are a function of the lag between them, but subsequently the individual with developed syntactic skill will employ both skills concurrently.

The results of this study might explain why so many previous studies have concluded that the single most important predictor of reading comprehension is phonological awareness and attribute no significant predictive role to either syntactic processing or working memory. As MacDonald and Christiansen (2002) pointed out, there are obvious concerns in the literature about the validity of the operationalisation of the key constructs, and despite the best efforts in this study to correct this problem, the same issue has emerged. What this study has demonstrated is that older children do rely on syntactic processing for better levels of reading comprehension, but as with the other constructs, a particular basal level is sufficient.

The results from these data suggest the possibility that phonological and syntactic processing might be related through the activities of the phonological loop. Breaking the phonological code is thus not only a necessary requirement for learning to read but continues to be a requirement of reading to learn. The implication is that the relationship between the two modes of processing should be viewed as reciprocal and not unidirectional as might have been supposed. The two processes are typically presented as being of a different order from one another, e.g., one is presented as "top-down" and the other as "bottom-up" implying fundamentally different activities. It is possible however, that syntactic processing represents an added sophistication to the coding process to accommodate more complex texts, in a manner which serves the purpose of avoiding the situation where an individual's ability to read is restricted by something as elementary as memory capacity. The resultant effect would be to reduce demand on working memory where it might otherwise have expected such demand to increase. This would help to explain conditions such as hyperlexia, whereby a child may acquire good phonological skills yet have serious comprehension difficulties.

This study has produced evidence that the processes involved in reading comprehension by teenagers are different from those employed by younger children who are learning to read. Specifically, competent teenage readers have developed and employ syntactic processing along with phonological processing in order to comprehend texts that are structurally challenging. The increasing complexity of texts would appear to play some part in the development and use of syntactic processing, but given the gender differences between students of similar ability, the role of the text is not a complete explanation. What is clear

is that some minimum level of competence in both phonological and syntactic processing is necessary for competency in reading comprehension beyond the early stages of learning to read. What that minimum level is, has not been identified in this study.

The study has also produced some evidence that the phonological loop within working memory plays a small but significant role in reading comprehension, but that the central executive has no predictive power. This result is more consistent with a unitary model of working memory than the multi component model that informed the methodology. It seems likely that the part played by working memory is restricted to a coding and storage role. This leaves a question as what sort of memory function, if any, facilitates the reflective aspect of syntactic processing. It has been suggested that syntactic processing may be linked to coding and storage through working memory, thereby reducing the demand on memory as opposed to increasing it. This possibility offers an interesting direction for future study.

The study also produced some interesting results indicating gender differences in relation to the processes involved in reading comprehension. The results support the view that boys and girls have different learning styles. This is an area that merits further study given current public concerns regarding the poor academic performance of boys in general compared to the performance of girls. In recent decades much work has gone into improving the academic outcomes of girls on the general assumption that relative performance was largely a consequenc of expectation and opportunity. The gender differences produced in this study suggest the possibility that there are

much more fundamental difference between boys and girls that might play a role in relative academic performance.

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Appendix A

Introductory Letter to College Principal

10thMarch 2003

The Principal

___________ College

___________WA

Dear ____________,

Request for access to conduct research.

As you are aware I am currently engaged in preparing a thesis, which will complete the requirements for Honours in psychology at Edith Cowan University. Professor Alison Garton is supervising my research. I plan to undertake a study of the respective roles of phonetic and syntactic processing and working memory in reading comprehension among teenagers. Given the topical nature of literacy in schools and the difficulties a small number of high school students face in this area, it seemed a topic worthy of further research. My proposal has been approved by the faculty ethics committee at the university.

For the purposes of the study I will be seeking a sample of 60 year-8 students who will be tested in relation to reading comprehension, phonetic and syntactic skills, and working memory. This will involve about an hour of each students time. I would propose that parents be given the option of whether this is carried out during school hours or not, but that all testing be conducted on the school campus. This testing would be spread over a three month period around second term. I am seeking your permission to access students in year 8 at ______________ College and carry out the testing.

Should you agree to my request for access to __________ year-8 students I plan select 2 houses at random and write to the parents of year 8 students seeking their permission for their children to take part. I will also seek the permission of the students when the parent has given approval. In the event that I do not get 60 subjects from 2 houses I may have to write to parents from a third house to make up the sample.

If you have any questions or concerns about the proposed study please let me know or alternatively contact Alison Garton at Edith Cowan University (tel: 9400 5110, email: a.garton@cowan.edu.au). Alternatively if you would like to speak to someone who is independent of the project you can contact Moira O'Connor, Honours Coordinator in the Department of Psychology (tel: 6304 5593).

I look forward to your response,

Yours sincerely,

John V. Holsgrove

Introductory Letter to Parents/Guardians

17th March, 2003

Dear Parents/Guardians

READING RESEARCH PROJECT

As part of my ongoing professional education I am undertaking a research project under the supervision of Professor Alison Garton at Edith Cowan University. This project is concerned with exploring certain cognitive factors that are believed to influence reading comprehension. The research proposal has ethical approval from the faculty at Edith Cowan University and the support and approval of the college principal, _________.

I am seeking 60 participants for this study from our current Year 8 students and would like your approval for «FIRST_NAME» to be tested by me for the purposes of the study. The testing will measure aspects of the student's phonological and grammatical skills, and working memory. This will involve about 1 hour of the students time which can be arranged in school time or, if you prefer, outside of normal school hours.

Students' individual test scores will be confidential. Should the testing produce any cause for concern in relation to an individual student's performance then I will discuss this with the respective parents in due course.

I would be grateful if you would complete the enclosed form and return it to me at the College by the commencement of Term 2. In the event that you approve of your child's participation I will also require «FIRST_NAME»'s agreement.

If you have any questions or concerns about your child's participation please contact me at the College. Alternatively, you can contact Professor Garton (6304 5110) or Dr. Moira O'Connor (6304 5593) at Edith Cowan University.

Yours sincerely

Mr John V. Holsgrove

Parent/Guardian Consent Form

PARENT/GUARDIAN CONSENT FORM

Project Title: Phonological processing, syntactic processing, and the role of working memory in reading comprehension among high school students.

I ___________________________ (the parent/guardian of the participant) have read and understood information provided in the letter accompanying this consent form. Any questions I have asked have been answered to my satisfaction.

I agree to allow my child ____________________ (name) to participate in the testing associated with this research and I understand that I, or my child, can withdraw consent at any time.

I agree that the research data in this study may be published, provided my child and my child's school is not identifiable in any way.

___________________________   ___________________

Parent/Guardian's signature   Date

If you require further information about this project please contact John Holsgrove (9307 2000), or Professor Alison Garton, School of Psychology, Edith Cowan University (6304 5110). If you wish to contact someone who is independent of the research project, please contact Dr. Moira O'Connor (6304 5593) School of Psychology, Edith Cowan University.

Child Consent Form

CHILD CONSENT FORM

Project Title: Phonological processing, syntactic processing, and the role of working memory in reading comprehension among high school students.

I ______________________(participating student) have been given an explanation of the research and the part I will play in it. Any questions I have asked have been answered to my satisfaction.

I ____________________ (name) agree to participate in this research and I understand that I can withdraw my consent at any time.

I agree that the research data in this study may be published, provided my identity and my school is not identifiable in any way.

______________________ ______________

Participant's signature Date

Appendix B

Data Disc

Appendix C

Working Memory Test Battery – Record Form	attached
Woodcock Reading Mastery Test (Revised) – Record Form	attached
TORCH Answer Booklet B	attached
TORCH Answer Sheet	attached
Syntactic Processing Test Stimulus Books	attached
Syntactic Processing Test Questions	attached

Note: The only copies of the Syntactic Processing Test Stimulus Books are attached to the first copy of the thesis.

SYNTACTIC PROCESSING TEST QUESTIONS

Each question is prefaced:
I will now read you a statement and I would like you to tell me if it is 'true' or 'false'.

SO Form 1

SO Test	The snake drank the water.	False	☐
SO1	The robber hated the mother.	True	☐
SO2	The painter noticed the problem.	True	☐
SO3	The man invited the captain.	False	☐
SO4	The king rode the car	False	☐
SO5	The artist drew the child.	True	☐
SO6	The deer entered the field	True	☐
SO7	The pig chased the dog.	False	☐
SO8	The manager carried the suitcase.	False	☐

SOForm2

SO1	The mother dropped the glass.	True	☐
SO2	The painter knew the boyscout	False	☐
SO3	The captain built the stage	False	☐
SO4	The prince taught the king.	False	☐
SO5	The child broke the chair.	True	☐
SO6	The tiger watched the deer.	True	☐
SO7	The dog ate the trash.	False	☐
SO8	The manager blamed the waiter.	True	☐

SS Form 1

SS Test	The mouse surprised the farmer.	False	☐
SS1	The lawyer upset the prisoner.	True	☐
SS2	The principal used the phone.	True	☐
SS3	The cow kicked the horse.	False	☐
SS4	The soldier wrote the letter.	False	☐
SS5	The fireman stopped the plumber	True	☐
SS6	The banker left the office.	True	☐
SS7	The artist phoned the doctor	False	☐
SS8	The frog left the tree	False	☐

SS Form2

SS1	The prisoner stopped the fight.	False	☐
SS2	The janitor tripped the principal.	False	☐
SS3	The cow Broke the gate.	False	☐
SS4	The painter insulted the soldier.	True	☐
SS5	The plumber heard the shout.	False.	☐
SS6	The banker attacked the girl.	True	☐
SS7	The doctor watched the movie	True	☐
SS8	The monkey followed the frog.	True	☐

CVP Form 1

CVP Test	The farmer paid the woman.	False	☐
CVP1	The teenager left the driver.	False	☐
CVP2	The animals ran up the hill.	False	☐
CVP3	The animals warned the owl.	False	☐
CVP4	The patient kept the nurse awake.	False	☐
CVP5	The cat chased the rabbit.	True	☐
CVP6	The teacher stopped the lesson.	True.	☐
CVP7	The coach cleaned the edge of the pool.	True.	☐
CVP8	The groom left the church.	True	☐

CVP Form 2

CVP1	The driver drove the car.	True	☐
CVP2	The chicken saw the fox.	True	☐
CVP3	The animal left the tree.	False	☐
CVP4	The patient upset the nurse.	False	☐
CVP5	The rabbit enjoyed the hunt.	False	☐
CVP6	The teacher taught the students.	True	☐
CVP7	The swimmer helped the coach.	False	☐
CVP8	The bride blamed the groom.	True	☐
Total Score		☐	