BEHAVIORAL AND ELECTROPHYSIOLOGICAL INVESTIGATIONS OF SEMANTIC PROCESSING IN SKILLED AND LESS-SKILLED COMPREHENDERS

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Theorists of reading comprehension failure are split between two groups: those that posit low-level word reading skills and phonological awareness as underlying factors of poor comprehension ability and those that consider poor comprehension as partially independent of these low-level skills. Several studies with children have now demonstrated that poor comprehenders with adequate decoding skills make up a small but significant proportion of poor readers. One promising hypothesis posits that semantic processing deficits underlie these children's comprehension difficulties. This hypothesis was supported by findings that demonstrated less-skilled comprehenders to show poorer than average performance on a variety of semantic tasks. In order to test whether these findings would generalize to adult poor comprehenders, we evaluated the dissociability of high-level and low-level skills in adults. In addition, we evaluated whether adult less-skilled comprehenders (with adequate decoding abilities) have semantic processing difficulties. A PCA compared the reading skills of large group of college aged readers and found that high level skills such as reading comprehension and vocabulary were partly dissociable from low-level reading skills such as decoding ability. Furthermore, in order to evaluate the semantic processing deficit hypothesis, adult skilled and less-skilled comprehenders were compared on several behavioral and electrophysiological tests of semantic and phonological processing. The findings from these studies revealed that less-skilled comprehenders generated fewer semantic associates in a verbal fluency task and showed reduced categorical priming in an automatic semantic priming task. Additionally, electrophysiological records of less-skilled comprehenders differed from skilled readers during a semantic processing task but no during a phonological processing task. Taken together these findings provide evidence that supports semantic knowledge/semantic processing differences between skilled and less-skilled comprehenders. Implications of these findings are discussed within the construct of an experience based model of semantic knowledge acquisition.

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1. CHAPTER 1

1.1. INTRODUCTION

Research has shown that both children and adults can have difficulties with reading comprehension that stem from multiple sources (Oakhill & Garnham, 1988). Factors such as listening comprehension, vocabulary, and decoding speed have all been shown to be significant predictors of comprehension skill in adults and children. However, underlying causal factors of both children's and adult's comprehension failure have yet to be identified and deserve further investigation.

It is now well established that less-skilled comprehenders are more likely than their peers to have difficulty with conversion of graphemic information into phonemic information (Beck & Juel, 1992; Vellutino & Scanlon, 1987). This finding has led some researchers to postulate that facility with word level and sub word level processing is the primary determinant of comprehension skill (Goswami & Bryant, 1990; Perfetti, 1985; Perfetti & Hart, 2001). Proponents of this viewpoint point to the fact that children and adults must be able to read words before they can comprehend text. This indisputable fact and the robust correlations between word and non-word reading performance and comprehension skill are the primary pieces of evidence for their hypothesis (see Perfetti, 1985). Although low level difficulties can certainly cause difficulties with reading and hence reading comprehension, recent research suggests that the two abilities; facility with comprehension and facility with decoding are separable. The primary evidence for this hypothesis comes from studies that have identified populations of children who have comprehension problems despite normal decoding skill (Oakhill & Cain, 2000; Nation & Snowling, 1998).

These two hypotheses, those positing low level causes of comprehension failure, and those positing higher-level causal factors for comprehension failure, are rarely fully tested. In particular, research that has focused on higher level contributions to comprehension failure has rarely made attempts to control for decoding ability. The failure of such studies to include appropriate word reading controls has left low-level reading factors difficult to rule out of any causal hypothesis of reading comprehension failure (Perfetti & Lesgold, 1979; Perfetti, 1985; Perfetti, Marron, & Foltz, 1996). Even studies that claim to have ruled out low-level reading factors often fail to include *appropriate* decoding controls. For example, researchers often use a "decoding" test that requires word reading in context, which has been demonstrated to have a bootstrapping effect (Perfetti & Hogaboam, 1975). On the other side, studies that have identified low level factors as primary in comprehension failure often combine less-skilled comprehenders with less-skilled readers and thus necessarily find low level factors to be deficient in their less-skilled comprehenders. It is important that comprehension difficulty not be confused with general reading difficulty. Less-skilled readers have been shown to have phonological processing difficulties that are thought to be the primary source of their reading difficulty (Vellutino & Scanlon, 1987; Vellutino, Scanlon, & Spearing, 1997). However, A growing body of work that has included appropriate decoding measures (word reading in isolation or non-word reading) has found reading and listening comprehension difficulties in children with normal decoding abilities (Oakhill & Cain, 2000; Oakhill, Cain & Bryant, 2003; Stothard & Hulme, 1992). This condition has been termed Specific Comprehension Deficit (SCD) (Cain, Oakhill & Bryant, 2000).

Researchers estimate that readers with SCD make up as much as 10- 15% of readers in the seven to eight year old age range (Stothard & Hulme, 1995). Recent studies have demonstrated that SCD children can have trouble generating text appropriate inferences (Oakhill & Cain, 2000), monitoring their comprehension progress (Oakhill et al., 2003), using relevant semantic information (Nation & Snowling, 1998), processing syntactically complex sentences (Hagvet, 2003), and holding information online in working memory (Oakhill et al., 2003), all despite normal single word reading ability. That decoding ability was normal in all of these cases suggest a different causal factor underlying these children's comprehension difficulties.

Although substantial evidence has now been provided to validate the existence of children with specific comprehension deficits, there is little consensus as to the cause of such comprehension difficulty. Many problems associated with less-skilled comprehension have been used as causal hypotheses in their own right. More specifically, correlational relationships between one ability (e.g., inference making) and skill in reading comprehension have been interpreted as causal relationships, with a deficit in a particular skill being implicated in causing comprehension failure. This method has lead to the development of several disparate theories of reading comprehension difficulty, none of which are able to capture all of the difficulties associated with reading comprehension failure. For example, children who have specific comprehension impairments have difficulty making several types of inferences when reading connected discourse. This has led some researchers to postulate the theory that skill at inference making leads to skill at reading comprehension (Cain & Oakhill, 1999). Evidence for this theory comes from studies that use comprehension age matched (CAM) controls. CAM readers are younger than the less skilled readers in question, but score similarly on tests of reading comprehension. In other words, the CAM group has chronological age appropriate reading comprehension but the older readers are reading below what their chronological age would predict. For example, researchers have demonstrated that CAM readers are actually better at generating relevant inferences than are older, less skilled readers (Cain & Oakhill, 1999; Oakhill & Cain, 2000). Although an interesting finding, as a causal hypothesis its scope is limited to explaining correlations between inference making and comprehension skill and it is unable to explain why other skills, such as vocabulary, are deficient in less-skilled comprehenders.

Another example comes from studies of comprehension monitoring, an ability that has been closely linked with comprehension skill (Nation, Snowling, & Clarke, 2005; Oakhill et al., 2003; Perfetti, Marron & Foltz, 1996). Monitoring skill, like inference making skill has been implicated as a causal factor of comprehension skill. But what skills are recruited for monitoring? Some researchers have posited that working memory is the underlying deficit causing both difficulties in comprehension monitoring and in inference making. Support for this proposal comes from relatively high correlations between comprehension ability and performance on traditional assessments of working memory. These correlations, along with poor performance on inference making and monitoring tasks have led some researchers to postulate a resource limitation hypothesis (Just, Carpenter, & Keller, 1996; Just & Carpenter 1992). According to this theory, the small working memory "capacity" of such readers directly limits the operation of language comprehension processes. This theory is based on evidence of correlations between comprehension skill and working memory performance, however these. WM tasks tend to draw heavily on reading comprehension skills and phonological processing skills, thus making any correlations circular (Waters & Caplan, 1996). Moreover, capacity in these theories isn't well defined. Does capacity refer to a processing limitation or a storage limitation or both? Although inference-making, comprehension monitoring, and working memory are probably all important for reading comprehension, as causal hypotheses, they each fail to explain all of less-skilled comprehenders' difficulties (e.g., vocabulary difficulty).

One promising hypothesis proposed by some researchers is that a semantic processing deficit may lie at the heart of these readers' poor comprehension ability (Nation & Snowling, 1998; 1999). Support for this hypothesis comes from findings that show SCD children to have semantic processing difficulties in a variety of tasks. More specifically, readers with comprehension impairments: 1) are significantly slower than normal at reading exception and low frequency words (surface dyslexic-like pattern) (Nation and Snowling, 1998; Perfetti & Hogaboam 1975); 2) generate fewer semantic category members in a verbal fluency task (Nation & Snowling, 1998); 3) have trouble judging synonyms, demonstrating difficulty with receptive as well as productive semantics (Nation & Snowling, 1998, 1999); 4) show selective deficits for low imageability or abstract words relative to concrete words in semantic judgment task and in recall tasks (Nation & Snowling, 1999); 5) and have poor performance on a number of traditional assessments of vocabulary knowledge (Nation, Adams, Bowyer-Crane, & Snowling, 1999), although some groups have identified SCD readers with age appropriate vocabulary knowledge (Cain et al., 2000). These findings led Nation and Snowling (1998; 1999) to suggest that semantic knowledge, independent of phonological knowledge, can directly affect reading comprehension. Furthermore, there is some evidence that the semantic deficit may be specific to certain types of relationships. For example, Nation & Snowling (1999) found that SCD readers show functional semantic priming (hammer – nail) and priming for categorically related items that were highly associated (cat-dog) but no priming for categorically related items that are not commonly associated (nose– head). Both control adults and children showed priming for all pair types. This suggests that the associations between functional relations are intact, but that the connections between categorically related items are weak. Interestingly, functional relationships are the first to be built up in children and often the last to degrade in patients with progressive semantic disorders (Lambon Ralph, Patterson, Gerrard, & Hodges, 2003).

The idea that less-skilled comprehenders may have semantic processing problems is not entirely new. In the 1970's Perfetti, Hogaboam, and Bell (cited in Perfetti & Lesgold 1979) showed that poor readers were slower in a categorization task but not in a picture-word matching task, indicating semantic processing difficulties above and beyond word reading. Furthermore, Howell and Manis (1986) demonstrated that poor readers show a particular difficulty in verbally listing members of superordinate categories relative to basic level categories, suggesting problems beyond word retrieval and naming that may be category specific.

Additional support for the semantic deficit hypothesis comes from comparisons of SCD children's performance to the performance of individuals with semantic dementia[1] . Many patients with semantic dementia show more difficulty reading or identifying low frequency words relative to high frequency words as well as difficulty reading exception words (surface dyslexia) (Patterson & Behrmann 1997; Patterson, & Hodges, 1992). Additionally, patients with semantic dementia have trouble comprehending word meanings as well as meanings of longer texts (Patterson, & Hodges, 1992). Some SD patients also have difficulty producing low

[1] See Thomas & Karmaloff-Smith, 2002 for concerns about comparisons between patients and children with developmental disorders

imageability words (Ward, Scott & Parkin, 2000).[2] Furthermore, SD patients also show deficits in word recall tasks, especially for unfamiliar words (Knott, Patterson, & Hodges, 1997). It should be noted, however, that the behavior of semantic dementia patients generally involves more severe impairments in semantic memory as well as speech impairments (such as Wernicke's aphasia or word finding problems) which are not present in SCD readers. Additionally, the performance of SD patients on comprehension tasks is much poorer than that of SCD children. Furthermore, the children tested by Nation & Snowling (1998, 1999) had not experienced any known traumatic injury or disease (typical causes of semantic impairment). This suggests that SCD readers have a more modest semantic impairment that is only evident during certain language and reading tasks and has a more subtle cause of onset.

The semantic deficit hypothesis is appealing for many reasons: First, it proposes a semantic processing deficit that is early enough in processing that it can potentially explain both word level and text level difficulties. Second, it is more parsimonious than postulating multiple deficits (such as inference making and comprehension monitoring) to explain all of the difficulties that poor comprehenders show. That is, if less-skilled comprehenders have poor semantic processing skills, then this deficit could cause difficulty downstream with multiple text level processing problems such as inference making, comprehension monitoring and working memory. Processing of semantic information at both the word level and the text level is necessary to maintain coherence, hold information online in memory and make appropriate connections between bits of text.

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[2] Studies with severe patients have shown reverse imageability effects. Bird, Lambon Ralph, Patterson and Hodges, (2000) suggest that this reversal is due to the fact that low imageability words, such as "thing", are often higher frequency than high imageability/more specific words such as "robin" (often these patients are only able to produce a few high frequency words when describing a picture).

Although several pieces of compelling evidence have been presented they are certainly not conclusive. First, it is still unclear whether the deficit is due to a developmental lag. Some studies have shown word level semantic differences to dissipate when reading age match controls were used (Stanovich, Siegel & Gottardo 1997). More specifically, Stanovich et al., (1997) tested less-skilled readers on their ability to read irregular words and non-words. They found that when these readers were compared to a chronological age control (as used by many researchers to define dyslexics e.g. Coltheart & Leahy, 1996) a significant number of readers with surface dyslexic reading patterns emerged and a significant number of readers with phonological dyslexic reading patterns emerged, however, when younger (reading age matched) controls were used, only poor readers with phonological dyslexic reading patterns were present. This finding suggested that any semantic difficulties (irregular and low-frequency word reading difficulty) may have been specific to underdeveloped children. Testing with adults would help clarify these issues and establish whether the deficit is specific to children or applies to less-skilled comprehenders in general.

The current thesis tests the semantic processing deficit hypothesis by comparing adult skilled and less-skilled comprehenders' performance on a range of behavioral semantic tasks and by comparing their event related potentials (ERPs) to a range of semantic tasks. By combining behavioral and neurophysiological methods and by using a fully developed adult population we hope to provide a more conclusive evaluation of the semantic deficit hypothesis.

1.2. THESIS OUTLINE AND RESEARCH CONTRIBUTIONS

One goal of this thesis is to characterize the reading ability profiles of adult readers. In particular, we sought to isolate and examine the often ignored population of readers that have poor comprehension skills relative to their word reading ability and to identify some of the other skills that are weak in this population. Furthermore, the set of experiments contained in this thesis was designed to further develop the hypothesis proposed by Nation and Snowling (1998; 1999) that the comprehension difficulties of less-skilled comprehenders stem from a semantic processing deficit. Because adults represent a fully developed population, testing on this population will allow us to rule out any type of developmental disability or lag. Moreover, testing the semantic deficit theory with adult less-skilled comprehenders will allow for a more thorough investigation of the hypothesis by using more direct designs, including brief exposure and ERP, which are difficult to conduct with children.

In Chapter 2 we present results from a principle components analysis conducted on a large database of adult readers that point to the partial dissociability of higher level skills such as reading comprehension, vocabulary and print exposure from lower level skills such as decoding and spelling. These findings demonstrate that although correlations exist between comprehension and word reading ability, inter-correlations between certain skills such as comprehension and vocabulary are much greater than the correlations between other skills such as comprehension and decoding. Descriptive statistics on the database show that a significant population of college readers has higher level difficulties, (e.g., comprehension) despite normal decoding and spelling skills. Furthermore, we show that this population is larger than the population with the reverse dissociation of poor low level reading skills and good comprehension. These findings are consistent with findings from the literature on children's comprehension difficulties that found a significant number (as much as 15%) of less-skilled comprehenders to have normal decoding skills (Nation & Snowling, 1998; 1999; Oakhill, 1994).

Chapter 3 describes the results from two behavioral investigations of semantic processing in skilled and less-skilled comprehenders. In these experiments, performance of less-skilled comprehenders with normal decoding abilities is compared to the performance of skilled comprehenders (matched on decoding and IQ) on two semantic tasks. Results from a verbal fluency experiment demonstrated that less-skilled comprehenders generate fewer semantic associates but not orthographic associates relative to skilled comprehenders. Furthermore, regression analyses demonstrated that comprehension (compared with vocabulary, print exposure, spelling and decoding) is the best predictor of performance on a semantic verbal fluency task.

In a second behavioral study, we provide evidence that less-skilled comprehenders have weaker automatic semantic processing skills. A semantic priming study with a very brief SOA found that skilled comprehenders show significantly more priming to targets preceded by categorically related primes (pig-horse) but not to targets that were preceded by associatively related primes (cat-dog) relative to less-skilled comprehenders. Along with a regression analysis that isolated comprehension as the best predictor of categorical but not associative priming, these findings suggest that less-skilled comprehenders have particular difficulty processing categorical relative to associative relationships.

In Chapter 4 we continued to probe the nature of the semantic processing differences between the groups by examining differences in the underlying neurophysiological activation. Using an event related potential (ERP) design, several components were identified that were sensitive to semantic processing in a semantic categorization task. First, we found the first neurophysiological evidence for the "associative boost" by demonstrating greater N400 reduction, MFN reduction and in N200 reduction for associative relative to categorically related targets. Second, we found several components to be sensitive to differences between skilled and less-skilled comprehenders during semantic processing tasks. For example, skilled and less skilled-comprehenders differed in the amount of N400 reduction for both associatively related and categorically related targets, with less-skilled comprehenders showing smaller reductions for both types of targets. Furthermore, we found that the differences in semantic processing were evident as early as 200ms. Less-skilled comprehenders showed smaller N200 reductions for associatively related and categorically related pairs in right frontal regions. A lack of late component differences in a semantic-picture processing task between skill groups suggested that the semantic processing differences of skilled and less-skilled comprehenders are limited to the linguistic domain. And finally we found that skilled and less-skilled comprehenders showed no differences in ERP response at any time point to a phonological processing task.

These findings provide additional evidence for the semantic deficit hypothesis put forth by Nation and Snowling, (1998; 1999) and they provide the first neurophysiological evidence for semantic processing differences between adult skilled comprehenders and less-skilled comprehenders.

Chapter 5 provides a summary and conclusions from the findings and will speculate on the potential sources of the semantic processing deficit in less-skilled comprehenders.

2. CHAPTER 2

Before we can begin to test the semantic deficit hypothesis with adult readers it must first be established that reading comprehension and decoding skill can be dissociated in adult readers. As discussed above, approximately 10- 15% of children with comprehension difficulties show adequate decoding skill. In order to determine if a similar population exists among adult less-skilled comprehenders, we examined adult performance across a variety of reading tasks thought to involve lower level and higher level written language processing. The idea that skill in comprehension processes and skill in lower level word reading tasks (decoding) can be dissociated is as controversial for adult populations as it is for children. Thus, to begin we examined a large database containing data from over 700 adult participants who took multiple reading tests designed to capture higher level abilities, such as reading comprehension, and lower level abilities such as decoding. In particular, we examined the factor structure of this database by determining which reading sub-skills (Comprehension, Vocabulary, Print Exposure, Decoding and Spelling) share the most variance. Furthermore, this chapter includes descriptive statistics that characterize the population of adult readers, including the frequency of adults who have discrepancies in their ability profiles. In particular we determine the percentage of adults that have difficulty with higher-level skills such as comprehension, despite normal low-level reading skills.

2.1. EXPERIMENT 1

2.1.1. Methods

2.1.1.1. Participants

1400 participants from the University of Pittsburgh community[3] took a battery of reading tests (described below) during the 2004/2005 academic year. Participants were recruited through the introductory psychology pool and through the University of Pittsburgh newspaper. All participants were native English speakers, with normal or corrected to normal vision. Subjects were screened for epilepsy, dyslexia and brain injury. Participants were compensated with credit required for completion of their introductory psychology class or with one payment of $7.

2.1.1.2. Procedure

All participants were tested on the 4th floor of the LRDC in the reading and language laboratories. All participants gave informed consent before they began the skill test set. The following skills were tested (with tests in parentheses): comprehension ability (Nelson-Denny), vocabulary (Nelson-Denny), decoding (sound-alike lexical decision), reading experience (author recognition), and spelling ability (spelling check off task). The comprehension subtest of the Nelson-Denny required participants to read a paragraph and answer questions about the content of that paragraph. Participants choose one of 5 possible answers to each of 36 questions. Participants were given 15 minutes to complete the task. The vocabulary sub-test of the Nelson Denny test provided a word and asked the participant to select the correct definition from a list of

[3] Most of the participants were University of Pittsburgh students, however, in order to get a greater amount of variance (especially at the low end of the spectrum); other members of the University community (e.g., staff) were recruited through a university newspaper advertisement.

5 possible choices (participants repeat this procedure for each of 100 words). Participants were given 7.5 minutes to complete as many items as possible. Both the Nelson-Denny comprehension and vocabulary sub-tests were scored in the same manner. Participants received 1 point for every question they answered correctly they received a 1/5 point deduction for each question they answered incorrectly or left blank. By using an equal deduction for wrong and blank answers, both speed and accuracy were taken into account in one measure. For the sound-out lexical decision task (our decoding measure) participants were required to sound out written pseudo-words and answer whether or not the letter string had the same pronunciation as a real word (e.g., *audishon)*. The scoring method used for this test was a standard *d'* calculation. The author recognition task was a list of names, many of which were common authors. The participant's task was to correctly identify the authors and avoid making false alarms to non-author foils (once again, a d' was calculated). Finally, the spelling test consisted of a long list of correctly and incorrectly spelled items. For this task participants were asked too check the correctly spelled items, and once again, *d'* was calculated for each participant.

2.1.2. Results

799 participants from the original pool of 1400 were included in the analyses. 601 participants were excluded because they failed to complete one or more of the tests included in the skill assessment battery.

First, a simple Pearson correlation was run on all of the tests given. Performance on all of the tests was correlated with performance on each of the other tests p <.05. However, some of the tests were more correlated with certain other tests (Table 2.1). In order to better characterize the structure of the data, a more complex measure that captures second order correlations was needed.

Table 2-1 Correlations between sub-tests

	Vocabulary	Comprehension	ART	Decoding	Spelling
Vocabulary	-	.644(**)	.544(**)	.209(**)	.275(**)
Comprehension	.644(**)	-	.441(**)	.153(**)	.244(**)
ART	.544(**)	.441(**)	-	.212(**)	.246(**)
Decoding	.209(**)	.153(**)	.212(**)	-	.303(**)
Spelling	.275(**)	.244(**)	.246(**)	.303(**)	-

** $p < 0.01$ (2-tailed)

A PCA was conducted on the data using two separate rotations; a Varimax rotation with a Kaiser normalization (gives an orthogonal solution) and a Promax rotation (gives and oblique solution). Using Kaiser's (1960) stopping rule, only eigenvalues greater that 1 were considered for component identification. That is, only eigenvectors or components that explained at least 10% of the total variance were included in the final solution (see Bryant and Yarnold, 1995; for a review of PCA methods).

The PCA, using the Varimax rotation, identified two components that together accounted for 68.2% of the variance (47.5% by the first, and 20.7% by the second). In this analysis we use a conservative cutoff of .5 (r=.5) for inclusion in a particular component[4]. In general, the larger the factor score of a variable (in this case variable = test), the more likely that score is to "belong" to that component (factor scores correspond to the correlation between a variable and the

[4] Typically values of .3 or greater are considered to "load on a component"; importantly, there were no variables that would have changed components if we had observed cutoff of .3.

component, i.e., factor score of .7 = *r*=.7). However, it is considered more important, for assigning variables to components, that variables should have a "large" loading only for one component (Bryant & Yarnold, 1995).

In the first component, Comprehension, Vocabulary and Author Recognition had factor scores greater than .5 (.869, .843, and .746 respectively), and Decoding and Spelling had factor scores lower than .5 (.059, and .225 respectively). In the second component Decoding and Spelling had factor scores greater than .5 (.847 and .743 respectively), and Vocabulary, Comprehension and Author Recognition had factor scores lower than .5 (.157, .079, and .191 respectively) (see Table 2.2). These results indicate that similar reading sub-skills underlie performance on comprehension, vocabulary and author recognition tests, and that these sub-skills are different from those reading sub-skills that underlie performance on decoding and spelling tasks. However, results from a PCA are not to be read as black and white, the approximate .5 cutoff for inclusion in a particular component is somewhat arbitrary. As Table 2.2 reveals, Spelling skills contributed somewhat more to component one than decoding skills did and that vocabulary and author recognition contributed somewhat more to component 2 than comprehension did. Because a Varimax rotation assumes orthogonality it forces factors into a particular component (doesn't allow for any inter-correlation between components). In order to confirm the solution found in the Varimax rotation, a Promax rotation was also conducted. Several researchers argue that a Promax rotation provides a more accurate solution because it allows for any inter-correlations that exist between components to be revealed (Dien, Beal, & Berg, in press; Hendrickson & White, 1964).

A PCA with a Promax rotation confirmed the findings of the Varimax PCA. Two factors were identified that together accounted for 68% of the variance (47.5 % by the first factor and 20.7 % by the second). In component 1, Vocabulary, Comprehension and Author Recognition all had factor scores above .5 (.879, .866 and .745 respectively) and Decoding and Spelling sub-tests have factor scores below .5 (-.084, and .108 respectively). In component 2, Decoding and Spelling had factor scores above .5 (.872, and .735 respectively) (see table 2). The Promax rotation does not assume orthogonality of components, thus, the orthogonality revealed in this PCA can be attributed entirely to the structure of the data. In this analysis there was even less overlap between the factors in the two components (all scores in the other factor are around or below .1). This analysis confirms the outcome of the first PCA and suggests that different sub-skills underlie performance on the tests identified in the two different components.**]**

Table 2-2 Varimax and Promax rotated component matrices

	Varimax		Promax	
	1	2	1	2
Vocabulary	.869	.157	.879	.011
Comprehension	.843	.079	.866	-.066
ART	.746	.191	.745	.068
Decoding	.059	.847	-.084	.872
Spelling	.225	.743	.108	.735

Despite the moderate correlations between all of the tests, the separation of test performance into two components suggests that there are two broadly defined “types” of reading ability. This separation also suggests that the tests identified within a component tap somewhat similar skills and that the tests that lie across components tap somewhat different skills. One question that arises is: what are the percentages of participants that score well on one component and not the other? To answer this question, two weighted factor composite scores were made for each participant by multiplying their normalized test scores by the corresponding factor score for each test (this was done for component 1 and for component 2). For example, for each persons' component 1 score, their vocabulary, comprehension and ART scores were weighted more highly than their spelling and decoding scores, and vice versa for each persons' component 2 score. The scores for each person on each component were then plotted, and split by the mean score on both components to create four quadrants: high on both, low on both, high on 1 and low on 2, and high on 2 and low on 1(Figure 2.1). As Figure 2.1 shows, individuals who scored well on both or on neither of the components were in the majority. However a number of people had a discrepancy between their two scores. In particular 187 out of 799 people (23%) scored in the average to high range on component 2 and in the poor range for component 1 only 68 (9%) of the individuals tested had the reverse discrepancy. Furthermore Figure 1 also illuminates the difference in spread for adult readers—the range of scores on component 1 is somewhat larger than on component 2, with a larger number of people falling in the average to good range on component 2. This suggests that few adult readers have poor low level orthographic and phonological skills but that relatively more adults have comprehension difficulty. By, adding the number of individuals scoring below average on component 2 we get 320 individuals, compared with adding the number of individuals who score below average on component 1, which gives us 439 individuals. That is, 55% of individuals are scoring below the mean on component 1, and only 40% of individuals are scoring below the mean on component 2. From this simple analysis it seems that the number of individuals with specific comprehension impairments (23% of individuals in our sample) is even greater in the adult population, relative to the child population. This is not a terribly surprising finding given that 1st grade children (the age range typically studied in studies of SCD) are still learning to decode and may still be struggling with low level word processing ability. It should be noted however that the spread of individuals in both the discrepant groups is not terribly large; most individuals tend to cluster toward the center without many individuals scoring more than one standard deviation below the mean on either component. Thus, the way in which "poor" or "good" on the components is defined will strongly influence the number of individuals in each group.

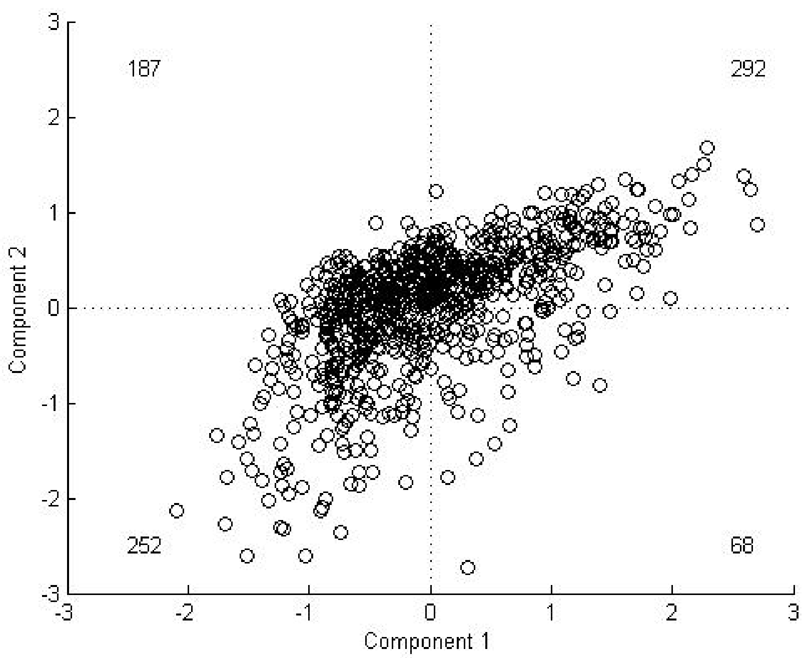

Figure 2-1 Individual scores on components 1 and 2

2.1.3. Discussion

These findings present compelling evidence that higher-level skills like comprehension and vocabulary can be partly dissociated from lower-level skills like spelling and decoding. Furthermore, these results show that there is a significant population of adult readers in that have poor higher-level skills, but have adequate or good low-level skills, and that the size of this group is at least as large as the number of children who meet this classification. Although we can conclude that different skills underlie performance on the tests that cluster in the two different components and that a sizeable number of adults may possess the skills required for adequate performance on one set and not the other (particularly those who perform adequately on tests of low-level processing but relatively more poorly on tests of higher-level processing), the question of what sub-skills underlie performance on the tests within each component remains. In particular, is the question of whether semantic processing is important for good performance on the tasks identified in component 1, namely reading comprehension. The following chapters will explore this question in detail by testing the semantic skills of adult less-skilled comprehenders.

3. CHAPTER 3

The results of the PCA and the descriptive statistics suggest that readers with specific high-level (e.g., comprehension) impairments are as common in the adult population as they are in children. Although adult readers can have higher-level reading problems in the absence of low-level word reading difficulties, the cause of their deficient skills remains a mystery. The goal of the behavioral experiments presented in this chapter and the next was to test the hypothesis that these readers (those that suffer from higher level difficulties despite adequate decoding) have a semantic processing deficit (proposed by Nation and Snowling, 19998; 1999). This hypothesis has been explored in children and several pieces of evidence point to its validity; however, critics question whether some of the "semantic deficits" seen in children with specific higher level difficulties are due simply to a developmental lag (Howell & Manis, 1986; Stanovich et al., 1997). Demonstrating specific higher level deficits in adults will provide a critical piece of evidence in support of the semantic deficit hypothesis. In order to test this hypothesis further we compared adult readers with poor comprehension to readers with adequate or good comprehension ability on tests of semantic processing. To ensure that we were comparing readers who differed only on comprehension ability, they were matched for non-word decoding ability using the Test of Word Reading Efficiency (TOWRE). Furthermore, to investigate the similarity of this group of readers to the readers identified as loading high on component 1 in experiment 1, all participants were also given the ND vocabulary, the check-off spelling test and the check-off decoding test (subset of the same tests given in experiment 1). In addition they were given a non-verbal IQ test (Raven's Matrices) to ensure that there were no differences in general intelligence. The 2 experiments presented in this chapter were modeled after tasks that have been used to tap semantic processing in children with poor comprehension ability (Nation & Snowling, 1998; 1999), and in patients with semantic impairments (Patterson & Hodges, 1992). The first experiment is a verbal fluency (VF) task that compares semantic and orthographic verbal abilities in skilled and less-skilled comprehenders. This task was chosen specifically because it is an explicit test of semantic knowledge that provides both a basic measure corresponding to the number of semantic associates produced for a given word or concept (Benton, 1968), and a more complex measure corresponding to the type of associates produced. The second experiment used a semantic priming paradigm to assess automatic semantic processing ability in skilled and less skilled comprehenders. In addition to assessing automatic semantic processing, the priming experiment will also compare different types of semantic processing by comparing associative and categorical priming across skill groups.

3.1. EXPERIMENT 2

The number of items produced to a semantic category (usually animals) in a verbal fluency task is thought to reflect ease of access to semantic representations. This task is often used to assess semantic memory loss in dementia patients (Barr & Brandt, 1996). Patients with semantic dementia usually show impaired production to semantic categories (fewer items generated) but normal production to letters relative to an age match normal control group. More recently this task was used by Nation and Snowling (1999) who found that, like dementia patients, children with poor comprehension produced fewer semantic associated but equivalent numbers of rhyme associates, suggesting a disturbance in semantic memory retrieval for less-skilled comprehenders. In this experiment we used a verbal fluency test to measure the overt semantic performance of skilled and less-skilled comprehenders.

3.1.1. Methods

3.1.1.1. Participants

65 members of the University of Pittsburgh community participated for monetary compensation. As discussed above, all participants were pre-screened on a battery of tests including the comprehension sub-test of the Nelson Denny (ND), the vocabulary subtest of the Nelson Denny (ND), a sound alike lexical check off task (decoding measure), a spelling check off test (all described in Chapter 1)[5] and the Raven's advanced progressive matrices (a test of non-verbal intelligence/spatial working memory[6]). Furthermore, each participant was given the test of word reading efficiency (TOWRE), a timed test which required participants to read as many non-words as they could, aloud from a list in 45 seconds. Their score was recorded as the total number read correctly minus the total number read incorrectly. Participants were selected based on ND comprehension performance, and were matched on decoding (TOWRE) and Raven's, but performance on the other test scores was not analyzed until after the experimental data was collected. This procedure allowed us to measure additional correlations between reading sub-test test performance and semantic skills (This testing procedure was used in Experiments 3 and 4 as well).

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[6] There is some debate as to exactly what the raven's test measures, especially with regard to whether the task requires sub-vocal rehearsal.

3.1.1.2. Procedure

All testing was done in the Reading and Language laboratories on the 4^{th} floor of The Learning Research and Development Center (LRDC) at The University of Pittsburgh.

Each participant was given a lined paper packet with four pages. Three of the pages contained a bolded letter at the top, either a “C”, “F” or “L”, and instructions to write down as many words beginning with the letter indicated as they could in the time given (these three made up the orthographic subtest). The 4^{th} page contained the bolded word “Animals” at the top of the page and instructions to write down as many animals as they could come up with in the time given (the semantic subtest). The participants were given 60 seconds for each page. The experimenter was in charge of keeping track of time on a stop-watch and told participants when to stop and start and when to flip to the next page.

3.1.2. Results

Using a median split based on ND comprehension score, participants were divided into two groups, 32 more-skilled comprehenders and 33 less-skilled comprehenders, matched on decoding ability, as assessed by the TOWRE and on Raven’s performance. The average comprehension score for the skilled comprehenders was 25.5/36 (SD=5) and was 13.2/36 (SD=3) for the less-skilled readers (out of a total of 36 points). On the TOWRE, skilled readers read 49/63 (SD=12) words on average and less skilled comprehenders read 51/63 (SD=7) words out of a total of 63 possible words. For the Raven’s skilled comprehenders = 7.9/32 (SD=3.9); less-skilled comprehenders =7.3/32 (SD=4) Comprehension scores were significantly different between the two groups, $p<.01$; decoding skill was not $p>.1$, nor was raven’s p>.1 (Table 3.1).

The average number of responses for the orthographic- VF test (the "C" "F" and "L" trials averaged together) and for the semantic VF test ("animals" trial) were computed and compared between the skilled and less skilled comprehenders. Planned comparisons revealed that skilled and less skilled comprehenders differed only on the number of animals generated (semantic task) $F = 5.09$, $p < .05$. They did not differ on the number of words generated to the letter stimuli $F = 1.974$, $p < .1$ (Table 3.1). Although performance on these two tasks is not normally tested for an interaction in the neurophysiological literature, for completeness we also conducted a repeated-measures ANOVA. Although the semantic task reached significance in the planned comparisons and the phonological task did not, the interaction between skill and verbal fluency task type was not significant $F < 1$. Skilled comprehenders generated more items in both tasks.

The results were subjected to a series of stepwise linear regressions. All of the tests from the assessment battery and the TOWRE were entered in as predictor variables. For the regression on number of animals generated, only comprehension was a significant predictor $r^2 = .11$, $t = 2.740$, $p < .01$. For the regression on number of words generated to C, F or L, only vocabulary was a significant predictor $r^2 = .073$, $t = 2.169$, $p < .05$ (see Table 3.2). That is, the more words participants knew the more words they were able to generate that began with a particular letter.

Table 3-1Results from an ANOVA comparing skilled comprehenders and less skilled comprehenders

	Less-Skilled Means	**Skilled Means**	**F value**	**P value**
Comprehension	13.2(3.3)	25.25(5.1)	127.915	**.000**
Vocabulary	37 (11)	57.8 (17.3)	32.923	**.000**
TOWRE	51.2(8.15)	49.37(12.2)	.511	.477
Semantic KF	25.6 (22)	19.88 (12.2)	1.718	.195
Semantic #	17	19	5.099	**.027**
Phonological KF	170(109)	179(269)	.030	.862
Phonological #	14(2.5)	17(9.5)	1.974	.165
Ravens	7.3(4)	7.9(3.9)	.455	.502
Spelling	.801(.12)	.83(.07)	1.525	.221
PA(elision)	.80(.165)	.81(.14)	.035	.852
Number of clusters	5.2(1.56)	5.5(1.56)	.216	.643
Number in each cluster	3.2(.79)	3.1(.72)	.016	.899
Imageability	3.7(.4)	3.9(.38)	1.60	.198

Standard deviations in parentheses

Table 3-2 Results from a stepwise linear regression for the "animals" and for the "letters" task

"Animals"	**Beta**	**t value**	**P value**
Comprehension	.331	2.740	**.008**
Vocabulary	.064	.360	.720
TOWRE	.122	1.004	.320
Ravens	-.136	-1.111	.271
Spelling	.091	.736	.465
PA(elision)	.078	.635	.528
"Letters"	**Beta**	**t value**	**P value**
Vocabulary	.109	2.169	**.034**
Comprehension	-.241	-1.328	.189
TOWRE	-.121	-.972	.335
Ravens	.072	.570	.571
Spelling	.128	1.025	.310
PA (elision)	.091	.721	.474

In addition to the standard measure on this task (number of items generated) we conducted three follow-up analyses in an attempt to understand further how skilled and less skilled comprehenders differ on this task: frequency, imageability and semantic clustering.

Processing of low frequency relative to high frequency words is thought to require a greater contribution from semantics. Because these words occur less frequently in daily use their orthographic/phonological to semantic connections are weaker and hence their retrieval from semantic memory is more effortful (Plaut, McClelland, Seidenberg, & Patterson, 1996). Evidence consistent with these claims comes from studies of individuals with semantic impairments. In general individuals with known semantic processing difficulty tend to show a preference for high frequency and regular word usage (Patterson & Hodges, 1992). Furthermore, children with specific comprehension impairments are slow to name both irregular words and low frequency words (Nation & Snowling, 1998). In order to assess the frequency of words produced by our skilled and less-skilled comprehenders, we compared the frequencies of the words they generated in the semantic and orthographic VF tasks. For our frequency analysis, the average Kucera and Francis (1967) written frequency for the orthographic VF test (the "C" "F" and "L" trials averaged together) and for the semantic VF test ("animals" trial) were computed and compared between the skilled and less-skilled comprehenders.

A one-way ANOVA found no significant difference in the frequency of the words generated, between skilled and less-skilled comprehenders for either the semantic or the orthographic verbal fluency task (all p values > .1) (Table 2.1). It is most likely the case that the lack of significant results in this measure resulted from the task demands. It is possible that the task structure is such that both groups of readers are inclined to generate high frequency items. If both groups of readers were forced to process (e.g., name) low and high frequency items, then a difference between groups on low frequency items might emerge.

Highly imageable words have more semantic features from multiple modalities compared with abstract words which have fewer semantic features, thus they have less robust representations. Past research has found that both patients with semantic impairments and children with specific comprehension problems show exaggerated imageability effects. For our imageability comparison, all of the words generated to the letter C[7], for all participants, were compiled (a total of 359 words) and then rated on a scale from 1-5 (1 being the least imageable and 5 being the most imageable) by 15 additional participants from the University of Pittsburgh community. These norms were then averaged across all words generated for the letter C for each participant in the experiment.

A one-way ANOVA found no significant difference between the imageability of the items generated by skilled comprehenders and less skilled comprehenders, $p<.1$ (Table 2.1). Like the frequency analysis, it is possible that both groups tended to generate imageable relative to abstract items when given the choice. Differences would be more likely to emerge if the task required processing of low and high imageability items.

Semantic clustering analyses are another common way to asses the structure of semantic memory. Although number of items generated in a semantic verbal fluency task is used to assess semantic processing, generally the clustering scheme used by a participant is thought to reflect frontal lobe, executive functions (Robert et al, 1997). Participants that generate more tightly

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[7] We restricted the analysis to words generated to the letter C in order to reduce the number of items that would need to be normed.

bound clusters are thought to have greater executive control over retrieval from semantic memory, whereas, those that have generally un-clustered sets are thought to have less control. For our semantic clustering comparison we calculated the number of "semantic clusters" within the animals sub-test and the number of items within each cluster. Clusters were defined as successively generated words that belonged to the same semantic subcategory (Troster et al, 1998). For example, farm animals, zoo animals, pets, rodents, beasts of burden and birds were all common categories. Two raters scored each of the tests independently.

Skilled and less skilled comprehenders did not differ in the number of clusters generated or in the number of items per cluster, p values >.1 (Table 1). Both groups of readers generated fairly well clustered lists. The results from this analysis suggest that skilled and less-skilled comprehenders do not differ with respect to controlled attentional retrieval from semantic memory.

3.1.2.1. Discussion

The results from this experiment indicate a relationship between comprehension skill and the number of animals generated in a VF task. Both a one-way ANOVA and a linear regression analysis found comprehension skill to be related to the number of animals generated. In contrast, comprehension skill was not related to the number of items generated in the orthographic fluency task.

Although these findings are suggestive of semantic processing differences in less-skilled comprehenders, we must interpret these findings cautiously, as the interaction between performance on VF task type and skill level failed to reach significance. Furthermore, the skill groups did not differ in several other analyses of the words they produced in the VF tasks (imageability, frequency and semantic clustering).

Another interesting finding from the regression analyses is that the tests which clustered together in component 1 of the PCA (exp 1) made different predictions with respect to semantic and orthographic performance in the VF task. Comprehension skill predicted performance on the semantic VF task, but vocabulary (which clustered with comprehension in the PCA) predicted orthographic VF performance. Although it's not surprising that vocabulary would predict performance on the orthographic VF task, it is interesting that vocabulary was not a significant predictor in the semantic VF task. These findings suggest that, although comprehension and vocabulary skills share variance, comprehension skill, independent of vocabulary knowledge, is related to semantic skills. Additionally, none of the skills from component 2 (Exp 1) predicted orthographic VF performance. This is most likely because the participants were matched on the TOWRE, and thus low-level skills were not a limiting factor in the number of words generated.

The results from Experiment 1 provided only weak evidence for semantic processing differences between skilled and less-skilled comprehenders. This may have been due to the relative ease of the task. Verbal fluency tasks have been primarily successful when used with patients who show severe semantic deficits. Given the more subtle nature of the deficits seen in less-skilled comprehenders it is possible that a more sensitive task is required to detect semantic processing differences. The goal of Experiment 3 was to examine and compare automatic semantic processing in skilled and less-skilled comprehenders by using a more sensitive measure: semantic priming.

3.2. EXPERIMENT 3

When participants are required to decide if a letter string is a word or not, they are faster to respond if the target was preceded by a semantically related word relative to an unrelated word; this facilitation is called semantic priming. Semantic priming is the most common experimental method for examining the structure of semantic memory in healthy adults (Hutchinson, 2003). Generally, researchers believe that semantic priming can occur by two mechanisms: automatic spreading activation and controlled semantic processing (Neely, 1977 although see Hutchinson, 2003 for comparison of feature overlap and associative strength theories of semantic priming). Controlled processing occurs at long stimulus onset asynchronies (SOA's) when subjects develop expectations about the target by strategically attending to semantic features. However, if SOA's are kept short (below 400 ms), priming effects are due to an automatic spread of activation between related concepts in memory (Neely 1977; 1991).

Some studies have demonstrated that the amount of semantic priming obtained is dependent on the type of semantic relationship the prime and target share (Chiarello, Burgess, Richards, & Pollock, 1990). Specifically, targets that are primed with a highly associated word that also shares category membership (e.g., cat-dog) typically show more priming than those primed with a categorically (non-associated) related word (mouse-gerbil). This phenomenon is termed the "associative boost" and occurs because categorically related items share features but items that are associatively and categorically related (from now on called associatively related) typically share features and co-occur frequently. Note, however, that there is some evidence that associatively related items also share more features (Lucas, 2000). Nonetheless when priming occurs for targets that are categorically but not associatively related to their primes, it is termed "pure" semantic priming. This type of priming has been used less frequently and is generally more difficult to find (see Hutchinson, 2003, for a review).

Semantic priming tasks have been shown in the past to be sensitive to semantic processing differences in patients with damage to semantic processing regions in the brain (Patterson & Hodges, 1992) and in children with poor comprehension (Nation & Snowling, 1999). In one study, using an auditory priming paradigm with 10 year old children, Nation and Snowling (1999) found no "pure" semantic priming for categorically related pairs (pig-horse) for poor comprehenders, but they did find priming for pairs that were associatively related (cat-dog) for poor comprehenders at relatively long SOA's[8]. Skilled-comprehenders, on the other hand, showed priming for both types of relationships. This difference can be explained if we assume that poor comprehenders have mild semantic impairments and that categorical relationships require a "deeper" level of semantic processing than associative relationships (whether due to additional feature overlap or an associative boost for associatively primed targets).

In order to examine automatic semantic processing ability, the current experiment required adult skilled comprehenders and less-skilled comprehenders to make lexical decisions in a visual priming task with very brief SOA's[9]. In our study, targets were primed with associatively related or with purely categorically related primes (compared to unrelated control primes). Skilled comprehenders were expected to show priming for categorically related pairs and for and associatively related pairs, with greater priming for the associative pairs (associative boost). Reduced priming in the less-skilled comprehender group for both types of primes

[8] Children in this study responded to both primes and targets so that the SOA was "self paced".
[9] Because we tested adults, we were able to use very short SOA's (unlike Nation & Snowling 1999) in order to ensure that our task was free of strategic processing.

(as seen in dementia patients) would indicate a relatively general processing deficit that affects both deeper feature based processing and associative relationship processing. However, reduced priming only for categorically related prime-target pairs would be consistent with a deficit that is relatively specific to conceptual level semantic processing.

3.2.1. Methods

3.2.1.1. Participants

60 participants from the University of Pittsburgh community participated for monetary compensation. All participants were pre-screened on a battery of tests in exactly the same manner as in Experiment 2.

3.2.1.2. Materials

The stimuli were prime-target pairs that had one of the following relationships: categorically related, associatively related, or unrelated. No phrasal associates were used (i.e., spider–web or cottage-cheese). Thirty pairs were categorically related, thirty pairs were associatively related, and one-hundred pairs were unrelated. An example of a categorically related pair is “lemon-orange”; and a pair that is associatively related is “cat-dog” (from here on referred to as associatively related). Primes and targets (particularly targets) were matched for frequency across all three conditions[10] and were normed for associative strength using the Edinburgh Associative Thesaurus (EAT) and Latent Semantic Analysis (LSA) to ensure that associatively related pairs were in fact more highly associated (Appendix A). Additionally there were one-hundred filler trials with pronounceable non-words as targets, all of the non-word targets were preceded by real word primes.

[10] Primary attention was given to matching target frequencies between the categorical and associatively related conditions, thus the other frequencies were not as well matches as we would have liked.

3.2.1.3. Procedure

All testing was done in the Reading and Language laboratories on the 4th floor of the Learning Research and Development Center (LRDC) at The University of Pittsburgh.

Participants were seated in front of a Dell computer, at a comfortable distance from the monitor where they made lexical decisions to target stimuli. Each trial consisted of a fixation cross that remained on the screen for 1000 ms, followed by a prime that remained on the screen for 70 ms, which was either categorically related to the upcoming target, associatively related to the target, or unrelated to the target, followed by the target item, which remained on the screen for 700 ms, or until the participant made a lexical decision with a key press. All primes and targets were displayed in black ink on a white background, and were presented in Arial font (Figure 3.2). All primes were displayed in lower case letters and all targets were displayed in upper case letters. Each participant saw each prime-target pair only one time, with no repeated stimuli. Trial order was random.

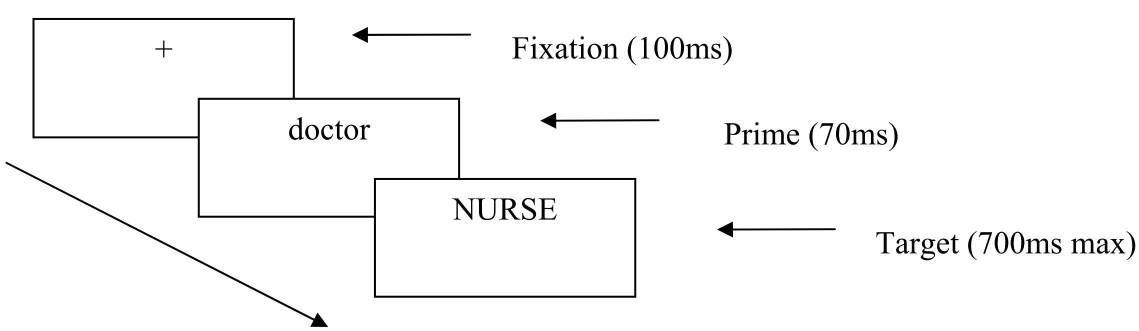

Figure 3-1Sample Trial

3.2.2. Results

Using a median split the participants were divided into two groups of 30 skilled comprehenders (ND Comprehension = 27.4/36; SD = 4.1) and 30 less-skilled comprehenders (ND Comprehension = 13.5/36; SD = 4), matched for decoding ability, (skilled comprehenders TOWRE = 52.3/63; SD = 8; less-skilled comprehenders TOWRE = 51.2/63; SD = 5.4) and Raven's performance (skilled comprehenders = 8.3/32; SD = 3.6 less-skilled comprehenders = 6.8/32, SD =3.7). Groups differed significantly on comprehension ability F= 164, p<.01, but not on TOWRE performance F<1 or RAVENS performance F<1 (Table 3.3).

3.2.2.1. Accuracy

A 3 (relatedness: unrelated, associatively related, categorically related) x 2 (skill: skilled comprehenders, less-skilled comprehenders) repeated measures ANOVA found a main effect of relatedness (p<.01) with the highest accuracy for associatively related targets (94%), the next highest accuracy was for categorically related trials (92%), and the lowest accuracy was for unrelated trials (85%). Pair-wise comparisons showed that each pair type was significantly different from each other pair type: unrelated- associative, p<.01, unrelated – categorically related, p<.01 and associatively related – categorically related p<.01. There were no other main effects or interactions.

3.2.2.2. Reaction time

As predicted, planned comparisons revealed that the skilled comprehenders had significantly greater priming for categorically related prime-target pairs than less-skilled comprehenders F = 6.2, p<.05, but they did not show significantly greater associative priming F <1 (Table 3.3;

Figure 3.3). This finding replicates the auditory priming findings of Nation and Snowling (1999). However, like Nation and Snowling (1999), the interaction between skill and prime type in a repeated measures ANOVA failed to reach significance $F(1,58) = 2.1$, $p = .13$, as both skilled comprehenders and less-skilled comprehenders showed the same general pattern of greater associative than categorical priming (Figure 3.3) . These findings provide evidence that less-skilled comprehenders have impoverished semantic representations; however, the lack of a significant interaction suggests that the effect is weak. Moreover, our findings suggest a deficit that is detectable even during an automatic processing task. These findings may also shed light on why pure categorical priming has been difficult to obtain in the past (Hutchinson, 2003). Specifically, if only skilled comprehenders show priming for categorical pairs, and a typical study includes a combination of skilled and less-skilled comprehenders, then categorical priming effects may have been weakened by the less-skilled comprehenders' data.

Table 3-3 Priming score means and results from a one-way ANOVA on the semantic priming results

	Less-Skilled	**Skilled**	**F value**	**P value**
Associatively related priming	20.68(29)	21.7(33)	.016	.901
Categorically related priming	2.9(25.3)	17.48(19.9)	6.154	**.016**
Comprehension	13.54(4.3)	27.42(4.1)	164.980	**.000**
Vocabulary	36(12.6)	63(13.3)	62	**.000**
TOWRE	51(5)	52(8)	.369	.546
RAVENS	6.8(3.6)	8.3(3.7)	2.139	.149
PA (elision)	.74(.18)	.79(.15)	.605	.441
Spelling	.81(.071)	.84(.07)	2.261	.138

Standard deviations in parentheses

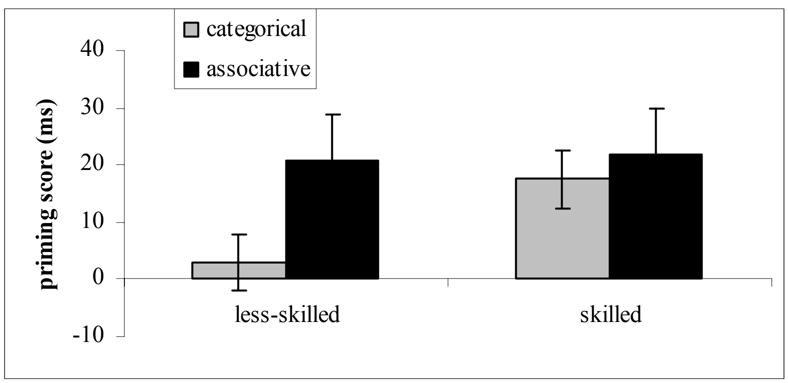

Figure 3-2 Priming scores in ms for skilled and less-skilled comprehenders

To help clarify our findings, stepwise linear regressions were conducted. All of the skill assessment variables were entered into two regressions: one for categorical priming and one for associative priming. Comprehension skill was the only significant predictor of categorical priming even when associative priming was entered into the regression model first; in contrast, phonological awareness was the only significant predictor of associative priming (Table 3.4).

These findings suggest that different skills might underlie processing of different types of semantic relationships. Specifically, lower-level skills, like PA contribute more to processing of associative relationships, whereas comprehension skill is related to categorical processing

Table 3-4 Results from step-wise linear regressions for categorical and for associative priming

Categorical priming	**Beta**	**t value**	**P value**
Comprehension	.339	2.154	**.038**
Associative Priming	.011	.069	.945
Vocabulary	.071	.460	.648
TOWRE	-.068	-.444	.659
Ravens	-.026	-.164	.871
PA (elision)	.201	1.310	.198
Spelling	.205	1.191	.241
Associative priming	**Beta**	**t value**	**P value**
PA(elision)	.422	3.046	**.004**
Comprehension	.024	.163	.871
Vocabulary	.223	1.650	.107
TOWRE	.039	.284	.778
Ravens	-.012	-.079	.937
Spelling	.143	.911	.368

3.2.3. Discussion

Although the interaction between comprehension skill and priming type failed to reach significance, the findings from the planned comparisons and from a linear regression suggest that greater comprehension skill is associated with greater categorical priming but not greater associative priming. These findings suggest a deficit in less-skilled comprehenders that is particularly apparent in processing of deeper, feature based relationships. Our findings are consistent with the results of an auditory priming study (Nation and Snowling, 1999) that demonstrated associative but not categorical priming for less-skilled comprehenders. Furthermore, our study added additional support for the semantic deficit hypothesis by finding differences between adult skilled and less-skilled comprehenders in semantic priming with very short SOA's (demonstrating differences in automatic processing).

It should be noted that, one potential reason for the lack of a significant interaction was the large variability of our sample (this was also true in Experiment 2). By choosing to use a median split to define our comprehension ability groups, it was necessarily the case that some participants showed a greater dissociation between comprehension ability and decoding ability. If a more stringent cutoff for inclusion in the skill groups had been used (e.g., top and bottom 25% on comprehension, matched for decoding), the interaction may have been more significant. Thus, the use of the regression data is critical for the interpretation of the results.

Findings from our regression analyses showed that comprehension was the only significant predictor of categorical priming (mirroring our regression findings for categorical priming). For associative priming, PA (Elision task) was the best predictor. The predictive power of PA on this task was somewhat surprising. Because of the lexical demands of our PA task, it is most likely that the relationship between PA and associative priming was mediated by lexical knowledge. In addition to being a written task (not auditory like most elision tasks) our elision task drew heavily on lexical knowledge because it required participants to create new words by manipulating phonemes from given words (e.g. "What word is left when you remove the /y/ sound from yachter?" Answer: Otter). Thus, our task was more influenced by lexical skills and less influenced by low-level manipulation of auditory sounds.

3.3. SUMMARY AND CONCLUSIONS

In this chapter we found that adult less-skilled comprehenders: 1) show reduced categorical priming and 2) generate fewer semantic associates produced in a verbal fluency task for less-skilled relative to skilled comprehenders. These findings are consistent with similar findings in children identified as less-skilled comprehenders (Nation and Snowling 1998; 1999). Furthermore due to the lack of significant skill by condition interactions, a series of stepwise linear regressions were conducted. These analyses confirmed the findings of the planned comparisons and showed a strong relationship between comprehension skill and categorical priming, but not between associative priming and comprehension skill. Furthermore, they revealed a relationship between comprehension skill and number of associates generated in a semantic VF task, but not between comprehension skill and number of associates generated in an orthographic verbal fluency task. It is also noteworthy that tasks which clustered together in our PCA (Chapter 2) were differentially good at predicting semantic performance. Comprehension predicted performance on tasks that required greater semantic processing (generating category members and categorical priming) whereas Vocabulary which were identified as belonging to the same component by the PCA, predicted performance on tasks that tapped word knowledge (generation of words that begin with a certain letter and amount of associative priming). This suggests that although performance on these tasks (Vocabulary and Comprehension) is correlated, they also tap some non-overlapping abilities—specifically comprehension is more dependent on semantic processing ability (beyond word knowledge) than the other two tasks.

In sum, our finding of no categorical priming for less-skilled comprehenders taken together with the regression findings that showed comprehension was the only significant predictor of categorical priming and of number of semantic associates generated provides additional evidence for semantic processing deficits in less-skilled comprehenders.

4. CHAPTER 4

Although the behavioral data were suggestive of semantic processing difficulty in adult poor comprehenders, the lack of skill by condition interactions leave the severity of the deficit open to question. A more direct measure, such as recording event related potentials (ERPs) during semantic processing tasks, is more sensitive to underlying processing differences and will help elucidate the nature of the deficit. ERPs provide a continuous record of brain activity from the beginning of stimulus onset that is temporally accurate to the mille-second. Thus, ERP's can provide information about cognitive processing that is not influenced by later stage processing, such as decision-making.

An ERP record is created by the activity of neighborhoods of neurons that sum to create electrical fields that can be detected with scalp electrodes. The voltage fluctuations in these fields are recorded and the resulting trace of voltage across time is called an electroencephalogram (EEG). An ERP is a subset of the EEG that is time locked to an event, such as the onset of a stimulus. ERPs to different stimulus conditions can then be isolated and compared. Thus, ERP is a direct measure of neural response to stimulus processing.

Critical to the usefulness of ERP recordings has been the identification of "components". Components are ERP patterns that are consistent across particular time points in particular regions for particular tasks. For example, studies have found early components (100-200 ms) corresponding to picture processing and processing of the orthographic components of words, somewhat later components (200 ms - 500 ms) corresponding to phonological processing and semantic processing and even later signals corresponding to sentence level or syntactic processing (600 ms) (Bentin et al., 1999; Kramer & Donchin, 1987; Rugg, 1984; Perez-Abalo et al., 1994). Furthermore, the size and shape of specific components will vary as a function of stimulus differences within a particular task.

In the current study we compared ERP's for skilled and less-skilled comprehenders in a semantic categorization task and mapped their recordings to previously identified components. In particular we focused on later components that have been shown to be sensitive to semantic processing (although, the entire waveforms were examined). A particular component of interest in this study was the N400. The N400 component, a scalp negative waveform that is most often found in central and parietal regions, has been associated with semantic processing and semantic incongruity. For example, when participants perform a categorization task or a semantic priming task, the N400 is larger (more negative) when the target stimulus is unrelated to the probe stimulus compared with trials where the probe word and target word "match" (see Hillyard & Kutas, 2002 for a review). Although the N400 response to semantic incongruity is extremely robust, this component is sensitive to other types of mismatch. For example, The N400 has also been shown to be sensitive to phonological mismatch in a rhyme task (larger N400 for non rhyming stimuli) or phonological oddball detection task (Kramer & Donchin; 1987; Radeau, Besson, Fonteneau, & Castro, 1998). Thus, the N400 is assumed to be discriminating between words that are expected and those that are unexpected (based on the pervious sentence or category) (Kutas & Iragui, 1998).In the current study, we expected that if less-skilled comprehenders had deficient semantic representations or had trouble accessing semantic representations, that their N400 response in a semantic task would be different from skilled-comprehenders'. More specifically, if less-skilled comprehenders are indeed deficient in semantic processing then we would predict a smaller N400 effect (reduction for related targets relative to unrelated targets) in our semantic categorization task.

Another component we set out to examine was a more anterior, negative going waveform termed medial frontal negativity (MFN). This recently identified component has also been identified in semantic processing tasks. The MFN is similar to the N400 in polarity and shape; however, it usually has a shorter duration, often occurs a bit earlier in processing, and has a more anterior location (Hamm, Johnson, & Kirk, 2002; Nobre & McCarthy, 1994). Several researchers have found this component to differentiate between semantically related and unrelated trials in a semantic priming task (Frishkoff, 2004) and in a sentence anomaly detection task (Frishkoff, Tucker, Davey, & Scherg, 2004; Nobre & McCarthy, 1994)[11]. As with our N400 prediction, smaller MFN effects in a semantic categorization task for less-skilled relative to skilled comprehenders would indicate semantic processing differences.

In addition to comparing semantic processing in general, the current experiment examines skilled and less-skilled comprehenders' ERPs to two types of semantic relationships in a categorization task (categorical and associative). As described in Experiment 3, categorical relationships are primarily feature-based as compared with relationships that are associative which also share features but get an additional boost from their high frequency of co-occurrence. If less-skilled comprehenders have a semantic processing deficit that is mild and thus particularly sensitive to semantic relationships that require feature comparisons, then they should show greater discrepancies from normal readers in their N400 or MFN waveforms for categorically related pairs than for associatively related pairs. More specifically, we would expect smaller

[11] This component is also referred to as the frontal N400 or the N300.

reductions for categorically related trials in particular for less-skilled comprehenders (thus mirroring our priming findings).

In this experiment we will also probe further the nature of the semantic processing deficit by looking at semantic processing in the non-verbal domain. All previous examinations of the semantic processing in less-skilled comprehenders have limited their investigations to verbal-semantic processing. In order to determine whether their deficit is limited to the access of semantic information from verbal labels, the current experiment will examine and compare ERPs in a picture categorization task. N400 and MFN reductions for semantically primed pictures have also been found in normal readers during picture processing (Hamm et al, 2002). Thus, deviant N400 or MFN waveforms for less-skilled comprehenders (smaller reductions for related trials) during semantic-picture trials will suggest a deficit that extends beyond verbal processing.

In order to conclude that less-skilled comprehenders have semantic deficits and not other lower-level reading impairments we also wanted to compare skilled and less-skilled readers on a lower-level word processing task. In particular, because of the robust correlations with grapheme phoneme awareness and reading ability in general (Vellutino & Scanlon, 1991) we chose to compare their processing on a phonological rhyme task (using presented visually homophone and non homophone pairs). As mentioned above, the N400 has also been shown to be sensitive to phonological mismatches (in addition to semantic mismatches). Several studies using a rhyme judgment task (with both auditory and visual presentation) have found smaller N400 when target stimuli have a similar pronunciation to probe stimuli relative to targets that are pronounced differently (Kramer & Donchin, 1987; Grossi et al, 2001). If less skilled comprehenders are also deficient in obtaining phonological codes from print, then their waveforms during our phonological task should differ from the waveforms of normal comprehenders'. In particular, less-skilled comprehenders' N400 responses should show smaller N400 reductions for phonologically similar trials than for to unrelated trials relative skilled-comprehenders if they have a phonological processing deficit.

4.1. EXPERIMENT 4

4.1.1. Methods

4.1.1.1. Participants

39 right-handed members of the University of Pittsburgh community participated for monetary compensation. All participants were pre-screened on a battery of tests in exactly the same manner as in Experiments 2 and 3.

4.1.1.2. Materials

The experiment was divided into three blocks: the semantic-word task block, the semantic-picture task block, and the phonological task block; each block used different stimuli.

For the semantic-word block we used the categorically and associatively related prime-target pairs from Experiment 3 (there were 30 associatively related pairs and 30 categorically related pairs) We also used the 100 unrelated word pairs from Experiment 3 (Appendix A).

For the semantic-picture task block, the picture stimuli consisted of pairs of related and unrelated pictures that were taken from the Snodgrass and Vanderwart (1980) normed line drawings. Related pictures shared category membership in one of the following categories: items of clothing, methods of transportation, animals, insects, body parts, furniture, vegetables or fruit. Unrelated pairs consisted of one member from one category and one member from a different category (no two items from overlapping categories such as vegetables and fruits or animals and insects were used to make an unrelated pair). One half of the picture pairs were semantically related (e.g., two animals) and one half of the stimuli were unrelated (e.g., an animal and an object). Participants were not given any information about the types of categories before the experiment began. All stimuli were shown only once and pairs were presented in random order.

For the phonological task block, 30 pairs of homophones and 30 pairs of non-homophones were used. Words that made up homophone pairs and those that made up non-homophone pairs were not significantly different in length, frequency or letter overlap (Appendix A). One half of the word pairs were homophones and one half of the pairs were non-homophones. All stimuli were shown only once and pairs were presented in random order.

4.1.1.3. Procedure

All testing was done on the 4^{th} floor of the LRDC in the reading and language labs. After Net application (see data acquisition and pre-processing), participants were seated in front of a Dell computer in a sound attenuated room. For each trial, in each block participants saw a series of two picture or word pairs, presented one at a time, separated by a blank screen, and were asked to decide if the two words they just saw were semantically related (in the first and second blocks) or if they had the same pronunciation (in the third block) (see figure 4.1). Participants pressed the "1"key on the number key pad for a "yes" response and the "2" key on the number key pad for a "no" response. The display of the stimuli was controlled by E-Prime software. In all blocks, during a given trial participants first saw a fixation cross (for 1000 ms), followed by the first stimulus (for 200 ms) and then by a blank screen (for 200 ms) and finally by the second stimulus (which remained on screen until the participant responded). All word stimuli were displayed in black ink on a white background in Arial font. For the word pairs the first word appeared in all lower case letters and the second word (the target) appeared in all uppercase letters. Pictures were also presented in black on a white background and were all the same size (Figure 4.1).

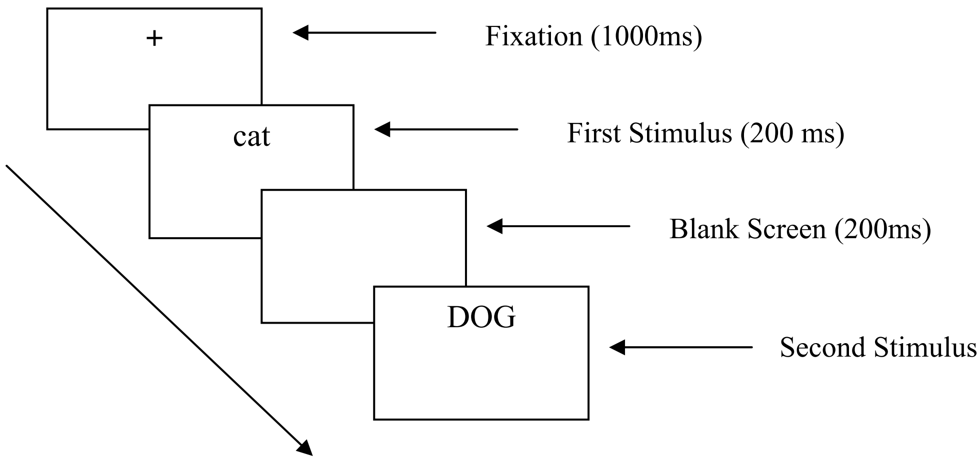

Figure 4-1 Sample trial presentation from the semantic-word task

4.1.1.4. ERP data acquisition and pre-processing

All participants were measured and fitted with an EEG recording net with a 128-channel electrode array and a vertex recording reference (Figure 4.2). Data were sampled at a rate of 1000 Hz (500 samples per second) and were amplified 1000 times and then filtered with a .01-hz high-pass filter. The data were then manually filtered with a 30-hz low-pass filter and segmented into 1,100 ms epochs starting 100 ms before the onset of the target word or picture. Segmented data were then averaged across trials and edited online for eye blinks and head movements. Participant's who had fewer than 15 good trials per condition were removed[12]. 9 subjects in all

[12] An exception was made for a few subjects who had less than 15 trials in one or more conditions but their remaining trials were very good.

were excluded. 30 remained in the final sample. After channel and subject exclusion the data were re-referenced to the average of the recording cites, and were baseline corrected (100 ms baseline correction tool). Data were then combined for statistical extraction and analysis or grand averaged for examination of topographic maps and topographic plots. Only ERP's to correct responses were entered into the final analyses.

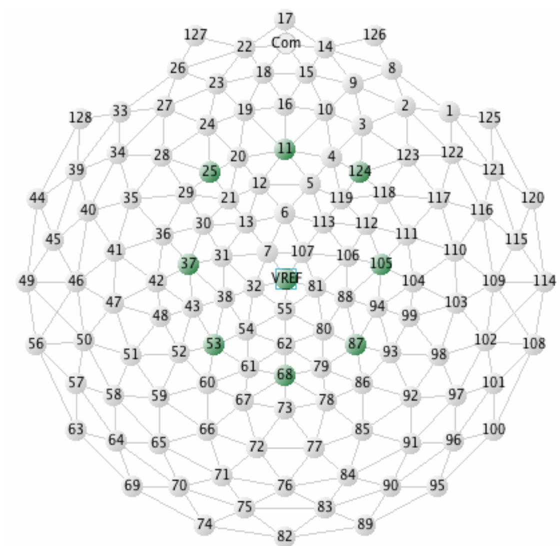

Figure 4-2 Schematic of a 128 channel net with the 9 electrodes of the international 10-20 system highlighted in green

4.1.2. Results

Using a median split the participants were divided into two skill groups of 15 skilled-comprehenders (ND Comprehension = 24.5; SD= 4.6) and 15 less-skilled comprehenders (ND Comprehension = 12.24; SD = 4.18), matched for decoding ability on the TOWRE (skilled-comprehenders = 52.9/63; SD= 6.1; less-skilled comprehenders = 55.1/63; SD= 5.8, and for general intelligence on the Ravens Matrices skilled-comprehenders = 8.0 SD = 3.1; less-skilled comprehenders =7.4; SD = 3.4. See Appendix B for the complete table of skill comparisons (additional skill assessments will not be discussed with respect to the ERP findings).

4.1.2.1. Behavioral data

For the behavioral data, two sets of repeated measures ANOVA's were run, one for on the accuracy results and one for the reaction time results. Overall accuracy was very high, all participants were better than 80% correct in all conditions.

Accuracy For the semantic word task, there was a significant effect of pair type $F(2, 56) = 33$, $p>.001$. Pair-wise comparisons revealed that all relatedness types were significantly different from all other relatedness types ($p<.01$). Participants were most accurate for associatively related pairs (96.6%) less accurate for unrelated pairs (96.3%) and least accurate for categorically related pairs (89%). There were no other main effects or interactions. For the semantic picture task, there were no main effects or interactions.

For the phonological task, there was a significant effect of relatedness $F(1, 28) = 8.8$, $p<.01$, with participants showing higher accuracy for related (M = 97%) compared with unrelated pairs (M = 95.6%). There were no other main effects or interactions.

Reaction time For the semantic-word task there was a main effect of pair type $F(2, 56) =40$, $p<.001$. Pair-wise comparisons revealed that participants had faster reaction times for associatively related pairs (615 ms) than categorically related pairs (722 ms) $p<.021$ or unrelated pairs (723 ms) $p<.021$.Categorically related and unrelated pairs did not differ ($p >.1$). There were no other main effects or interactions. For the semantic picture task there were no main effects or interactions.

For the phonological task, there was a main effect of relatedness $F(1, 28) = 5.29$, $p<.05$. Participants had faster reaction times to related pairs (607 ms) than to unrelated pairs (639 ms). There was also a main effect of comprehension skill $F(1, 28) = 4.36$, $p<.05$). Less-skilled comprehenders were slower overall (675 ms) at this task than skilled comprehenders (571 ms). There were no other main effects or interactions.

4.1.2.2. ERP data

For initial inspection, we viewed 128-channel waveform plots of the grand-averaged files for skilled comprehenders and for the less-skilled comprehenders. We compared ERP response to associatively related, categorically related, and unrelated targets; we then compared related and unrelated picture targets; and finally we compared waveform plots for homophonic vs. non-homophonic targets. We also viewed "students - test" topographic maps[13], set at $\alpha = .05$ for each task, for each condition within each task compared to each other condition in a particular task. Time points were selected for statistical testing based on both comparison of waveform plots and on the results from the students-t-test topographic maps. Table 4.1 shows the components that were singled out for statistical testing. All time points selected were subjected to a repeated-measures ANOVA on all 9 electrodes or for more localized components, a subset of the 9 electrodes of the international 10-20 system (F3,FZ,F4;C3,CZ,C4;P3,PZ,P4) (Figure 4.3). Interactions with skill were further subjected to pair-wise t-tests.

[13] The student's t test tool is available in the newest beta version of Netstation. Student's t test topographic maps have appeared in published work by Frishkoff et all, 2004.

Table 4-1Channels and temporal intervals of ERP components in Experiment 4

Component	Relevant Tasks	Channels Analyzed	Epoch	Procedure
N100/P100	Semantic-Pictures	- Frontal(F3,Fz,F4) - Central(C3,Cz,C4) + Parietal(P3,Pz,P4)	100-200 ms	Mean Amplitude Peak Latency*
N200/P200	Phonological Semantic-words	+Frontal(F3,Fz,F4) -Central(C3,Cz,C4) -Parietal(P3,Pz,P4)	150-300 ms	Mean Amplitude Peak Latency*
N400	Phonological Semantic-words Semantic-pictures Pictures	- Central (C3,Cz,C4) - Parietal(P3,Pz,P4)	300-800 ms	Mean Amplitude Peak Latency
MFN	Phonological Semantic-words Semantic-pictures	- Frontal(F3,Fz,F4)	300-500 ms	Mean Amplitude Peak Latency*

*Latencies were not measured all components because some components did not have clear peaks; + or – signifies the polarity of waveform

Semantic word task

N400 Figure 4.3 shows a large negative going waveform in central and parietal electrodes that began around 300 ms and continued until around 600 ms, the N400. This component was larger (more negative) for unrelated (black line) relative to related targets. Furthermore, on closer inspection the N400 is larger for categorically related targets (blue line) relative to associatively related targets (red line). As figures 4.3 and 4.4 show these effects are observable for both less-skilled comprehenders and for skilled comprehenders.

A 3 (relatedness: unrelated, categorically related, associatively related) x 2 (lobes: central, parietal) x 3 (hemispheres: left, medial, right) x 2 (skill: less-skilled comprehenders, skilled-comprehenders) repeated–measures ANOVA for average amplitudes between 300 ms and 600 ms on the posterior 6 electrodes of the 10-20 system showed a main effect of relatedness F (2, 56) = 46, $p<.001$, Pair-wise comparisons confirmed that each relatedness condition was different from each other relatedness condition (unrelated-associatively related, $p<.01$; unrelated- categorically related $p<.01$; categorically related-associatively related $p<.01$). Furthermore, there was a significant relatedness by lobe by hemisphere interaction $F(4,112) = 15.26$, $p<.01$ with a larger N400 effect in central and parietal regions and over the right hemisphere. Importantly, there was also a relatedness by comprehension skill by hemisphere interaction $F(4,112) = 2.7$, $p<.05$. Less-skilled comprehenders showed smaller N400 reductions for categorically related targets and for associatively related targets (particularly in the right and medial hemispheres) compared with skilled comprehenders. In addition, unlike skilled comprehenders, less-skilled comprehenders didn't show any additional N400 reduction for associatively related pairs relative to categorically related pairs, in the right, medial, or left hemispheres (no associative boost) (Figure 4.5; Table 4.2). These findings suggest that less-skilled comprehenders show differences with respect to both types of semantic processing (categorical and associative) when sufficiently sensitive measures are used.

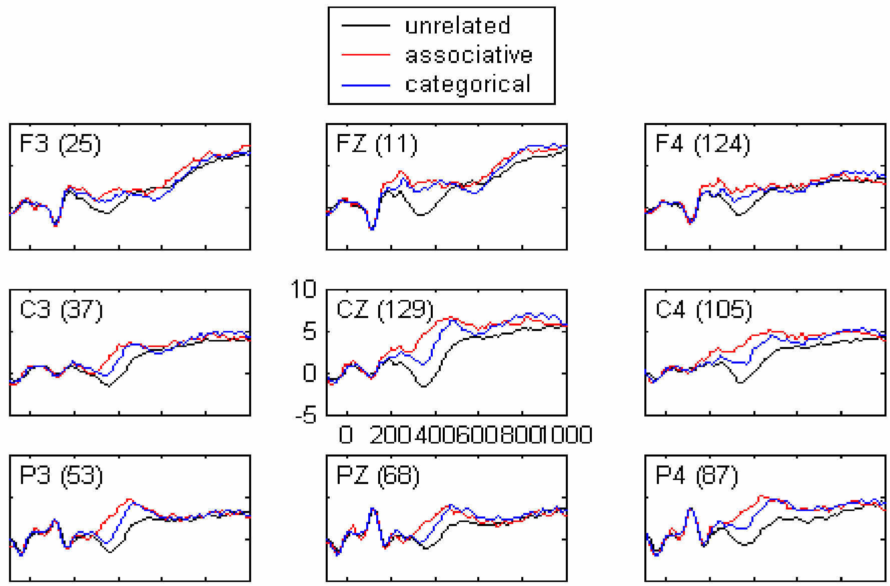

Figure 4-3 ERP response to unrelated (black), categorically related (blue) and associatively related (red) targets, for skilled comprehenders in the semantic-word task

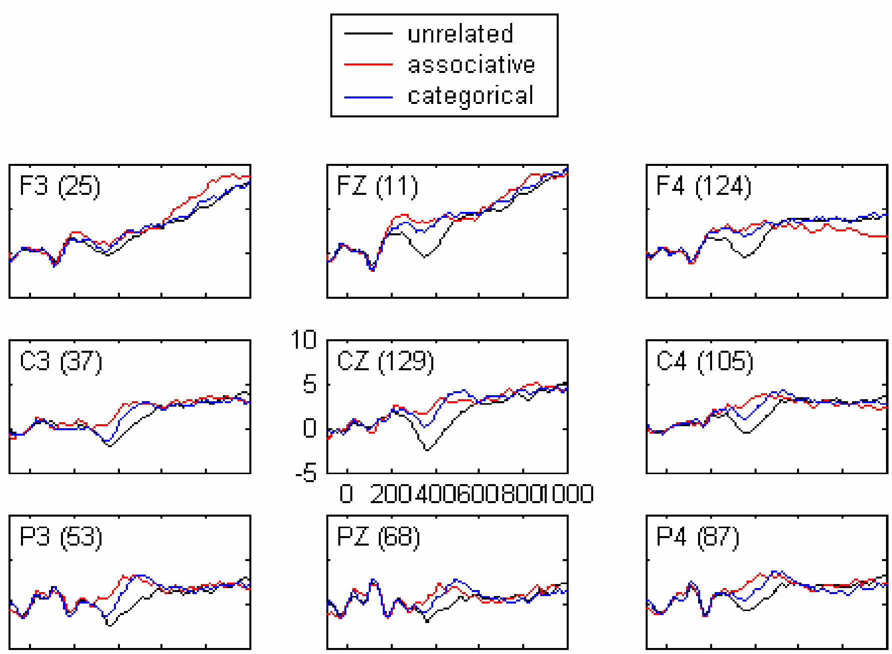

Figure 4-4 ERP response to unrelated (black), categorically related (blue) and associatively related (red) targets, for less-skilled comprehenders in the semantic-word task

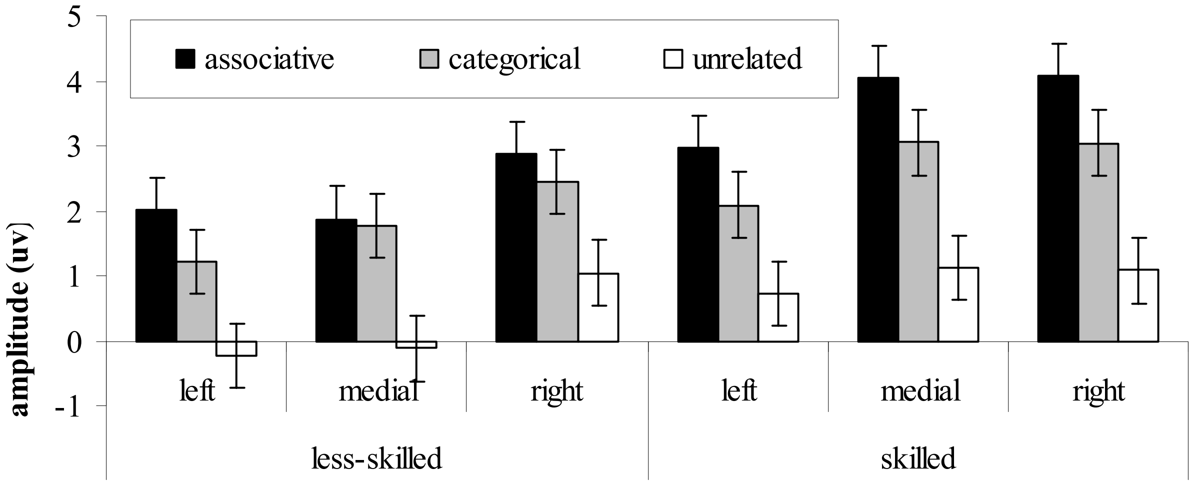

Figure 4-5 Average amplitude of the ERP response for all relatedness conditions, in left, medial and right hemispheres during the 300ms-600 ms time window in the semantic–word task

Table 4—2 Amplitude differences for left, medial, and right hemispheres, for skilled and less-skilled comprehenders, 300 ms -600 ms, for the semantic–word task

	Left			Med			Right		
	ass-cat	ass-unrel	cat-unrel	ass-cat	ass-unrel	cat-unrel	Ass-cat	ass-unrel	cat-unrel
Skilled	*.88	***2.2	***1.37	*1.0	***2.92	**1.92	*1.0	***3.0	***1.9
Less-skilled	.78	***2.2	**1.4	.09	**1.9	1.89	.42	***1.8	***1.4

*significant p<.05;** significant p<.01; ***significant p<.001

MFN In Figures 4.3 and 4.4, a smaller, shorter negativity between 300 ms and 500 ms can be seen in the three frontal electrodes. Because of its time course and anterior location we identified this component as the MFN (Frishkoff, 2004; Frishkoff et al, 2004). A 3 (relatedness: unrelated, categorically related, associatively related) x 3 (hemispheres: left, medial, right) x 2 (skill: less-skilled comprehenders; skilled comprehenders) repeated–measures ANOVA on the three frontal electrodes of the 10-20 system, compared responses between 300 ms and 500 ms and found a main effect of relatedness $F(2,56)=34$, $p<.001$. Both associatively related and categorically related targets were less negative than unrelated targets. Pair-wise comparisons revealed that each relatedness condition was different from each other relatedness condition (unrelated-associatively related, $p<.01$; unrelated-categorically related $p<.01$; categorically related-associatively related $p<.01$). There was also an interaction between relatedness and hemisphere $F(4,112) = 3.7$, $p<.001$. The MFN effect was larger over the medial and right hemispheres than over the left hemisphere. There were no significant main effects or interactions with comprehension skill for this component.

For a better characterization of the topographic differences between the N400 effect and the MFN effect, Figure 4.6 shows student's t-test maps for both the associatively related and the categorically related conditions and Figure 4.7 shows the same for less-skilled comprehenders. Darker shades correspond to greater amplitude differences (blue for negative differences and red for positive differences). The MFN is best seen at the 300 ms time window in anterior regions, compared with the N400 which is best seen in the 350 ms and 400 ms time windows in central and posterior regions. The differences between the skill groups in the size of the N400 can also be seen by comparing the 350 ms and 400 ms time windows between Figures 4.6 and 4.7.

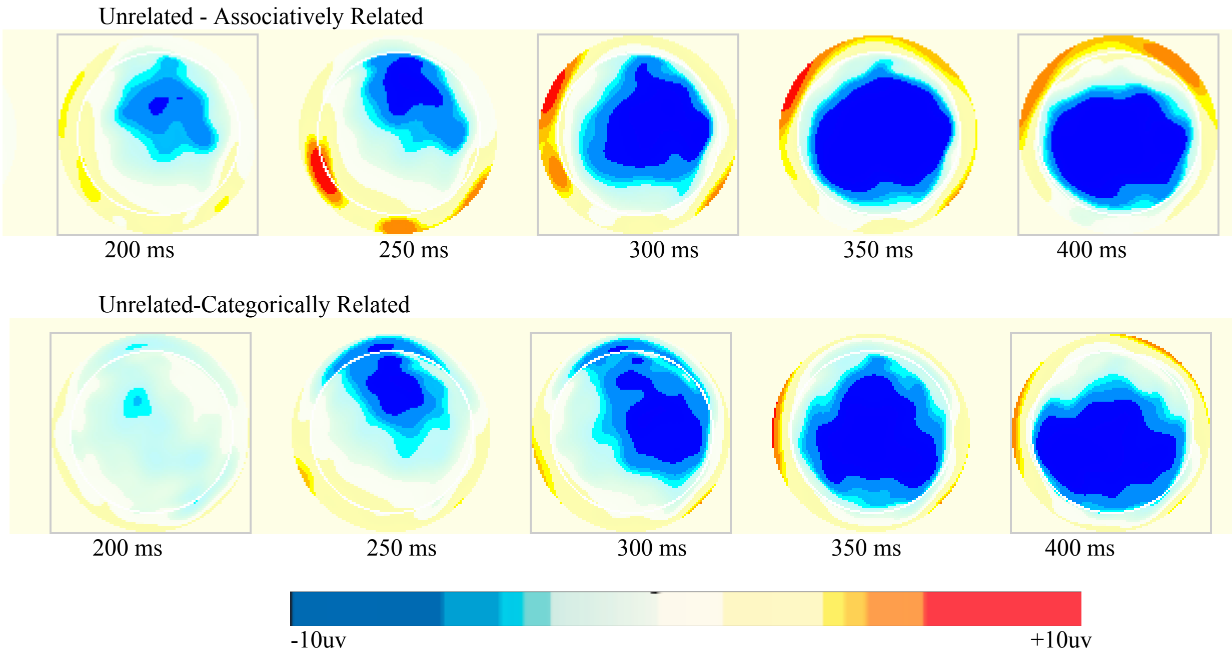

Figure 4-6 “Student’s t” topographic maps (α =.05) of the ERP response show condition differences for skilled comprehenders from 200ms – 400 ms, in the semantic-word task

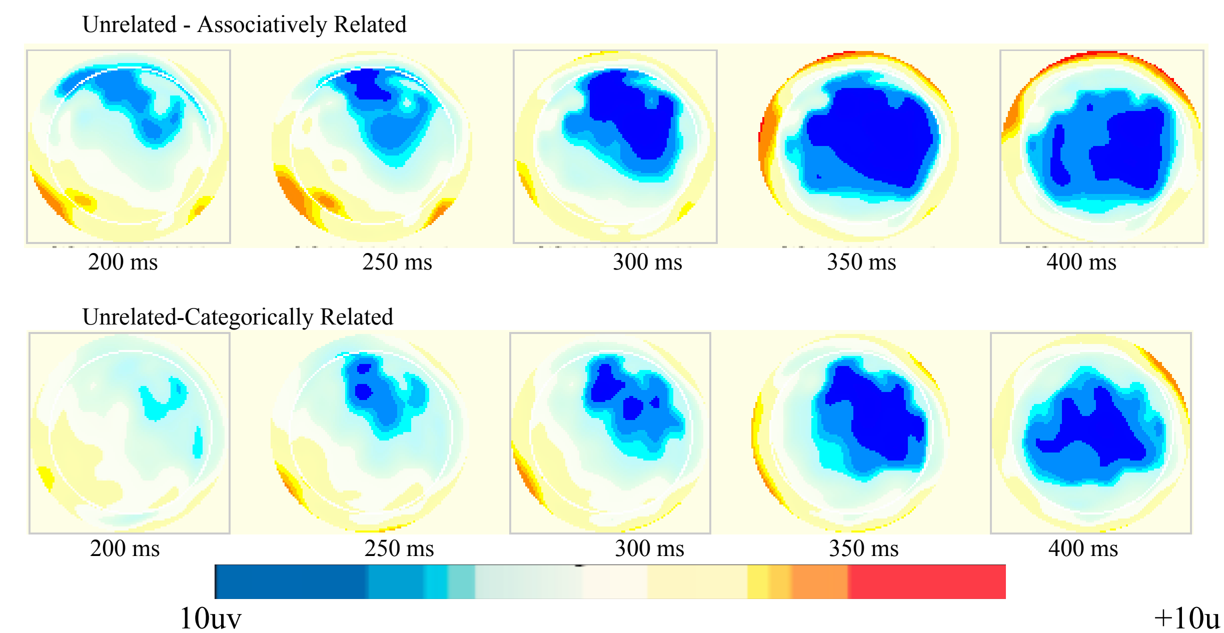

Figure 4-7“Student’s t” topographic maps (α =.05) of the ERP response show condition differences for less-skilled comprehenders from 200ms – 400 ms, in the semantic-word task

N2/P2 The earliest component that was sensitive to semantic processing was the N200/P200. This effect was not one that we set out to look for, but it was clearly visible in both the student's t-test topoplots and in the waveform plots (Figures 4.3 and 4.4; particularly electrodes CZ and FZ). This component is a negative going waveform around 200 ms in posterior electrodes, and a positive going waveform that contains a small negative waveform within it in anterior electrodes. The N200/P200 differences can also be seen in the "student's t-test" topographic maps shown in figures 4.6 and 4.7 at 200 ms[14]. This component can be distinguished from the MFN by its early time course and location, which is more posterior than the MFN. The N200 is most clearly seen in 4.6, as a small negativity (dark blue) in the associatively related - unrelated condition, for skilled readers at 200 ms.

A 3 (relatedness: unrelated, categorically related, associatively related) x 3 (lobes: frontal, central, parietal) x 3 (hemispheres: left, medial, right) x 2 (skill: less-skilled comprehenders; skilled comprehenders) repeated–measures ANOVA on the average amplitudes during the 150 ms - 250 ms time period, for the 9 electrodes of the 10-20 system, found a main effect of relatedness $F(2,56)=10$, $p<.001$. Pair-wise comparisons revealed that the associated response was significantly different from the categorically related response $p<.01$, and that the associatively related response was significantly different from the unrelated response, $p<.01$; however, the difference between the unrelated response and the categorically related response was only marginal $p=.08$. Furthermore, there was a significant relatedness by lobe interaction $F(4,112) = 4.0$, $p< .01$ and a significant relatedness by lobe by hemisphere interaction $F(8,224) =$

[14] Even though the waveform is primarily positive going in the frontal electrodes, it is the negative deflection within the positivity that differs for relatedness.

3.4, $p<.01$. There was greater N200/P200 sensitivity to semantic relationship in the frontal lobe and over the right hemisphere (see Figures 4.3 and 4.4). There was also a significant comprehension skill by hemisphere by relatedness interaction $F(4,112) = 5.0$, $p<.01$. Less-skilled comprehenders showed smaller N200/P200 reductions for related pairs (particularly associatively related pairs) in the medial and right hemispheres, but not in the left hemisphere, than skilled comprehenders (Figure 4.8; Table 4.3). The skill differences in this component were somewhat broader compared with the skill differences seen in the N400, with less-skilled readers showing no significant differences between any of the relatedness conditions[15]. Because of the lack of significant differences at this time point for less-skilled comprehenders, we concluded that skilled comprehenders activated semantic information earlier and thus their semantic effects can be seen sooner. It should also be noted; however, that skilled-readers also showed smaller differences between relatedness conditions for this component relative to the differences seen in the N400 component.

Latency Peak latency analyses were conducted for the N400 and MFN. There were no significant main effects or interactions with relatedness or skill (F>1). Latency analyses were not conducted for the N200/P200 effect due to the lack of a true peak in several electrodes. The lack of latency effects between skill groups is consistent with findings from the only other published ERP paper that compares adult skilled and less-skilled readers, Segalowitz, Wagner, and Menna (1992), which showed no latency differences between reading groups in their tasks.

[15] There was on significant difference in the left hemisphere between associatively and categorically related conditions—however this difference seemed to be driven by an inhibition effect between unrelated and categorically related pairs and thus it must be interpreted cautiously.

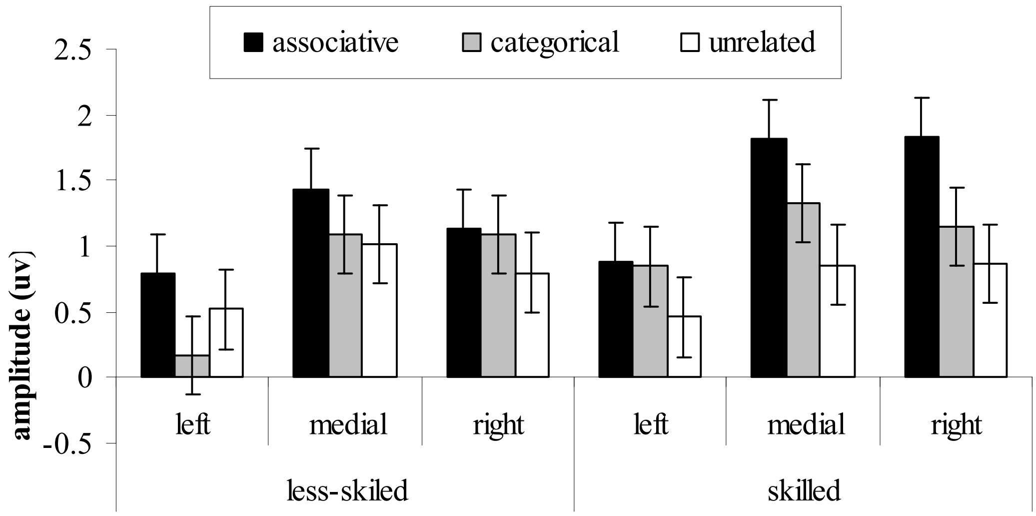

Figure 4-8 Average amplitude of the ERP response for all relatedness conditions, in left, medial and right hemispheres during the 150 ms -250 ms time window in the semantic–word task

Table 4-2 Mean amplitude difference for left, medial, and right hemispheres, for skilled and less-skilled comprehenders, 150ms -250 ms, for the semantic–words task

	Left			Med			Right		
	ass-cat	ass-unrel	cat-unrel	ass-cat	ass-unrel	cat-unrel	ass-cat	ass-unrel	cat-unrel
Skilled	.03	.42	.38	.49	**.96	*.47	*.68	***.97	.28
Less-skilled	**.62	.27	.34	.35	.42	.06	.04	.33	.28

*significant p<.05; ** significant p<.01; ***significant p<.001

Semantic picture task

N400 4.9 and 4.10 reveal a large N400 response with more negative going waveforms to unrelated pictures than to related pictures, this component began at 300 ms and continued until 600 ms. This N400 effect was largest in centro-parietal regions (although this difference is less clear for pictures than for words). A 2 (relatedness: related; unrelated) x 2 (lobes: central; parietal) x 3 (hemispheres: left; medial; frontal) x 2 (skill: less-skilled comprehenders; skilled comprehenders) repeated measures ANOVA on condition averages for the 6 posterior electrodes between 300 ms and 600 ms found a main effect of relatedness $F(1,28) = 7.4$, $p<.01$. ERP responses to related picture targets were more positive than ERP responses to unrelated picture targets. There was also a relatedness by lobe interaction $F(1,28) = 11.4$, $p<.01$ and a relatedness by lobe by hemisphere interaction $F(1,56) = 6.95$, p<.01. The N400 effect was larger in central than in parietal lobes and over the right and medial rather than the left hemispheres. There were no interactions with comprehension skill.

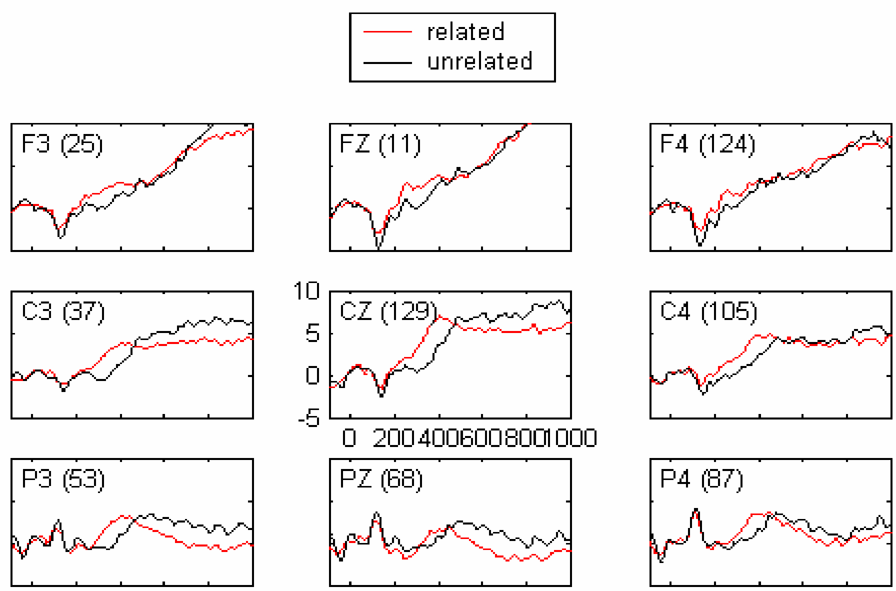

Figure 4-9 ERP response to unrelated (black) and related (red) picture targets for skilled- comprehenders, for the semantic-picture task

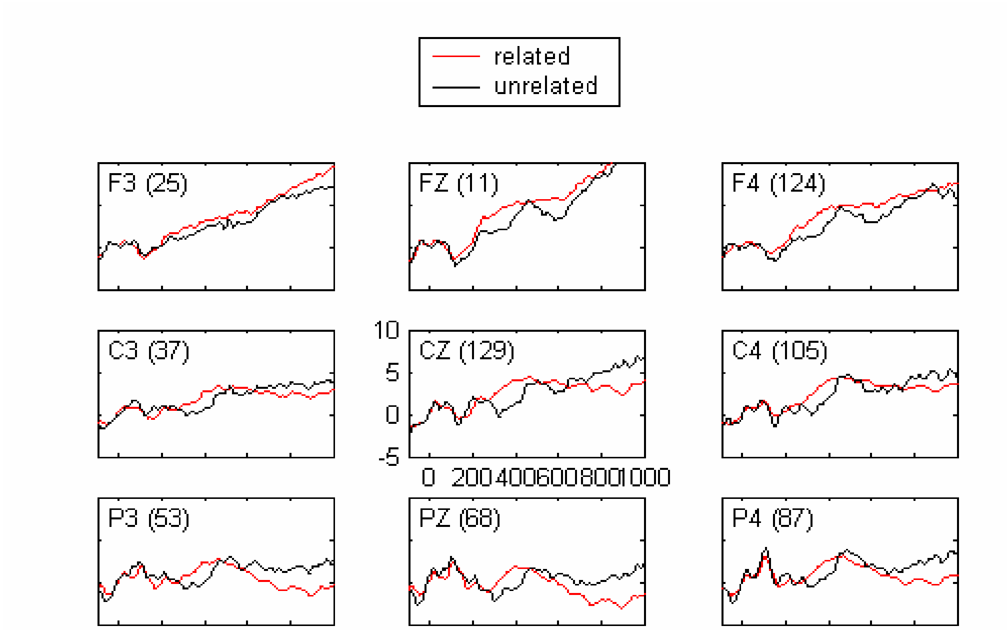

Figure 4-10 ERP responses to unrelated (black) and related (red) picture targets for less-skilled comprehenders, for the semantic-picture task

MFN As in the semantic-words task, ERP responses in the semantic-picture task show a smaller, but present MFN component in frontal electrodes, with responses to unrelated targets showing greater negativity than responses to related targets (Figures 4.9 and 4.10). A 2 (relatedness: related; unrelated) x 3 (hemisphere: left; medial; right) x 2 (skill: less-skilled comprehenders; skilled comprehenders) repeated measures ANOVA was conducted on the three frontal electrodes of the 10-20 system for the 250 ms-500 ms time range, and revealed a main effect or relatedness $F(1,28) = 43.8$, $p<.001$. Related targets were less negative than unrelated targets. There were no interactions with comprehension skill.

P100/N100 The earliest component that was sensitive to relatedness in picture processing appeared very early in picture processing, by around 100ms. This P100/N100 was negative going in anterior electrodes and positive going in posterior electrodes. This component has only recently been identified in picture processing and is considered to represent the combining of bottom up information with top-down information and is the first component to be sensitive to expectancy violations for picture stimuli (Federmier & Kutas, 2001).

A 2 (relatedness; related; unrelated) x 3 (lobe; frontal; central; parietal) x 3 (hemisphere; left; medial; frontal) x 2 (skill: less-skilled comprehenders; skilled comprehenders) repeated measures ANOVA on the 9 electrodes of the 10-20 system for the 100 ms – 200 ms time window found a main effect of relatedness $F(1,28) = 92$, $p<.001$. Unrelated targets were more negative at this point than related targets. Furthermore there was an interaction between relatedness and hemisphere $F(2, 56) = 8.5$, $p<.01$ and an interaction between relatedness hemisphere and lobe $F(4,112) = 18.2$, $p<.001$. As can be seen in figures (4.10 and 4.11) the reduction for related targets is more prominent in the frontal lobe (there is actually a slight reversal in the parietal electrodes as is common for P100 effects) and for electrodes and in the right hemisphere. There was also a relatedness by skill by lobe by hemisphere interaction. $F(4,112) = 3.67$ $p<.01$. Although four way interactions are notoriously difficult to interpret (and plot), looking at Figures 4.9 and 4.10 reveals a larger N100 reduction in the frontal lobe, left hemisphere electrodes for skilled comprehenders than for less-skilled comprehenders (less-skilled comprehenders effect seems more lateralized to the right hemisphere). Because of the difficulty in interpreting such interactions, this finding will not be discussed further. Further analysis, possibly including electrode clusters would be needed to clarify this effect.

Latency There were no main effects or interactions in any of the components during the picture-semantic task ($F>1$).

Phonological task

N400 As figures 4.11 and 4.12 show, the most prominent component in the phonological task is a large N400 waveform that begins at 300 ms and continues until 600 ms in the central and parietal electrodes. This N400 component is sensitive to relatedness in this task and is very similar to the N400 seen in the semantic tasks.

A 2 (relatedness; related; unrelated) x 2 (lobe; central; parietal) x 3 (hemispheres; right; medial; left) x 2 (skill: less-skilled comprehenders; skilled comprehenders) repeated measures ANOVA run on the posterior 6 electrodes of the 10-20 system, found a main effect of relatedness $F(1.28)=69.0$, $p<.001$., with non-homophonic targets having a more negative trajectory than homophonic targets. There was also a relatedness by hemisphere interaction $F(2,56)=28.3$, $p<.001$ and a relatedness by lobe by hemisphere interaction $F(2,56)=17.4$, $p<.001$. The N400 effect is largest in the central lobe and in the right hemisphere (Figures 4.11 & 4.12). There were no interactions with comprehension skill.

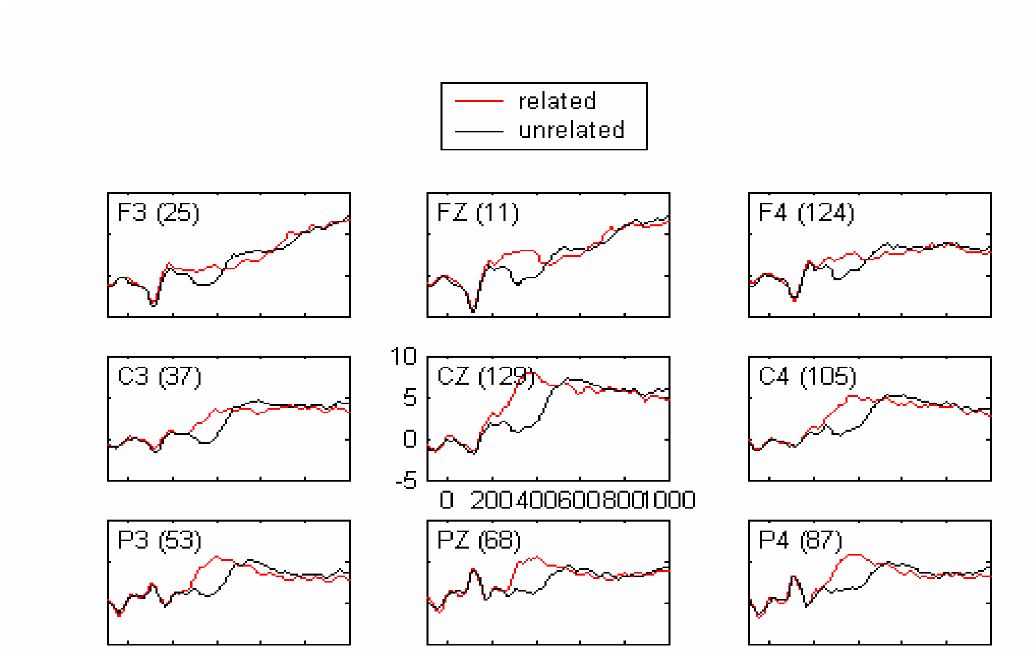

Figure 4-11 ERP response to unrelated (black) and related (red) targets for skilled comprehenders for the phonological task

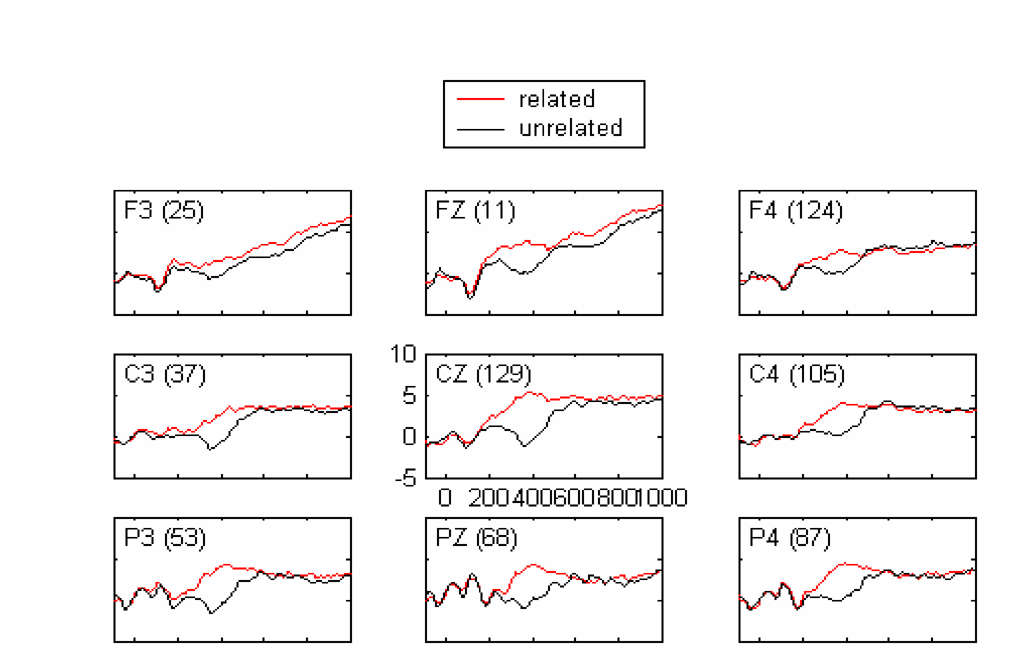

Figure 4-12 ERP response to unrelated (black) and related (red) targets for less-skilled comprehenders for the phonological task

MFN As in the semantic waveform plots, a medial frontal waveform that was more negative for unrelated than related targets can also be seen between 300 ms and 500 ms in the 3 frontal electrodes of the 10-20 system (Figures 4.11 and 4.12. This, previously unreported finding indicates that the MFN, like the N400 is sensitive to multiple types of stimulus mismatch.

A 2 (relatedness; related; unrelated) x 3 (hemisphere; right; medial; left) x 2 (skill: less-skilled comprehenders; skilled comprehenders) repeated measures ANOVA on the three frontal electrodes found a main effect of relatedness $F(1, 28) = 25.6$, $p<.05$. Non-homophonic targets produced more negative going waveforms at this time period than homophone targets. There were no interactions with comprehension skill.

N200/P200 As in the semantic words task, the phonological task produced a waveform peaking around 200 ms that was negative going in posterior regions and positive going in anterior regions (Figures 4.11 and 4.12). For this task, the N200 is much more clearly visible than the P200 and has a more pronounced peak. The anterior end of this component appears as a positive separation just before the MFN. This finding is consistent with results from previous ERP examinations of phonological processing that have found this component to be sensitive to phonological mismatches (Kramer & Donchin, 1987; although see discussion).

A 2 (relatedness; related; unrelated) x 3 (lobe; frontal; central; parietal) x 3 (hemisphere; right; medial; left) 2 (skill: less-skilled comprehenders; skilled comprehenders) repeated measures ANOVA run on the 9 electrodes of the 10-20 system for the 150 ms-250 ms time period found a main effect of relatedness type $F(1,28)=8.1$, $p<.01$. Non-homophonic targets were more negative than homophonic targets. There was also a relatedness by lobe by hemisphere interaction $F(4,112) = 5.8$, $p<.01$, with the largest reduction for homophone targets occurring in the frontal and central lobes and in the right hemisphere. There were no interactions with comprehension skill (F>1).

Latency Peak latency analyses are not reported for this task (For N400, MFN or N200) because clear peaks were difficult to identify. More specifically the prominent waveforms in this task had an overall positive going angle, which made negative peak comparisons difficult.

4.2. SUMMARY AND CONCLUSIONS

4.2.1. Semantic word task

Our results showed sensitivity to semantic relationships in the semantic-word task for the accuracy, reaction time and ERP data. Participants made more mistakes to categorically related targets than to associatively related targets and they were faster, to respond to associatively related targets than to categorically related targets. This difference suggests that categorical relationships were more difficult to evaluate than associative relationships. The behavioral results did not reveal differences between skilled and less-skilled comprehenders in either of the semantic tasks, which, given the ERP findings, suggesting that the behavioral measures were not sensitive enough to capture skill differences.

In the ERP record, the semantic word task elicited components that were sensitive to different types of semantic relationships and to differences in semantic processing between skilled and less-skilled comprehenders. In the semantic-word task both skilled and less-skilled comprehenders showed large N400 effects; however, the effects were larger for skilled comprehenders than for less-skilled comprehenders over the right hemisphere the region where the N400 is generally found to be the largest, (see Kutas & Van Petten, 1994, for a review), suggesting differences in semantic processing. In particular, less-skilled readers did not show as much of a categorical N400 or an associative N400 reduction as skilled readers. This finding points to differences in processing of both types of semantic relationships. Less-skilled readers also differed from skilled comprehenders in that they failed to show any additional N400 reductions for associatively related pairs above and beyond their reductions for categorical pairs. The finding, of smaller categorical reductions for less-skilled readers, is consistent with our behavioral priming results in which less-skilled comprehenders showed no categorical priming (here their N400 categorical reduction is significant, but it is smaller than for skilled comprehenders). However, our ERP findings with respect to associative processing are less consistent with our behavioral results, which showed no differences between the skilled and less skilled readers in associative priming. There are several differences between the two methodologies and tasks that may have contributed to the presence of associative differences in the ERP recording but not in the behavioral task. First, ERP measures neuronal firing, which will not necessarily be reflected in reaction time to the same degree; subtle differences in amplitudes may not necessarily cause reaction time differences. Second, the task used in the ERP paradigm was an overt task, which alerted subjects to the fact that some targets were related to each other; this could have produced greater categorical effects. Third, the ERP task was much slower; because it was an overt task no attempt was made to keep SOA's short. With greater processing time and with overt knowledge (which probably caused participants to attend to semantic relationships) differences in less-skilled comprehenders processing were more likely to emerge.

In addition to the N400 findings, we found a negative going waveform that was sensitive to semantic processing in anterior regions between 300 ms and 500 ms, which we identified as

MFN. This components shape and trajectory was similar to the N400 however, due to its anterior location it has been found to have a different cortical source. The N400 is thought to be generated by left hemisphere language processing regions such as Wernicke's area (Kutas & Van Petten, 1994), whereas the MFN has been localized to the anterior-cingulate (Frishkoff, 2004).Given it's source, the MFN, is thought to reflect direction of attention to stimulus features, whereas the most recent theories of N400 response suggest that it is primarily sensitive to violation of online predictions or expectancies. There were no differences between skilled and les-skilled comprehenders reflected in this component. This lack of apparent differences suggests that the primary difference in semantic processing between individuals lies not in the direction of attention to semantic features but in the generation of expectancies based on the processing of semantic features. However, due to the nascent understanding of the MFN, this interpretation should be considered speculative, and will require further research.

During the semantic-word task, an early N200 component was also sensitive to skill differences in semantic processing over the right hemisphere, which is suggestive of even earlier semantic processing differences between skill groups. Like the MFN, there is far less information on ERP's during this time window, elicited during semantic processing tasks than for the N400. A few studies have found very early components that were sensitive to semantic differences. For example, one study found an early anterior difference in negativity by 200 ms that was sensitive to semantic mismatch. However, although there was clear separation in their component for semantic mismatches by 200 ms, their waveform had a much later peak of 350 ms (Kutas & Iragui, 1998). Given the late peak and the general anterior negative trajectory (unlike ours which is generally positive going with a negative dip) of the wave their component was more likely to be part of the MFN component. More recently a study with children found differences in semantic processing (in an oddball categorization task) in anterior regions that peaked around 170 ms and was labeled a P200. Although this component looked very similar to ours in shape and location, the task difference and the fact that the study was conducted with children make it difficult to determine whether their component is the same one that we have identified here (Silva-Perea et al., 2003). Whether our anterior N200 component should be considered part of the MFN or its own component, differences in processing during the semantic-word task are indicative of an early (by 200 ms) sensitivity to semantic relationships that differs for skilled and less-skilled comprehenders.

4.2.2. Semantic picture task

In the semantic-picture task, a similar pattern of late component differences between semantic conditions emerged. The semantic-picture task elicited both a large N400 and MFN, with unrelated targets more negative than related targets. Both the N400 and MFN for picture mismatches that were similar in shape and location have been reported previously (Federmier & Kutas, 2001; Hamm et al., 2002). Neither of these components was sensitive to comprehension skill differences. The only component that was sensitive to skill differences during the semantic picture task was an early anterior negative N100 component in frontal and central regions. The N100 has only been shown to be sensitive to semantic differences in one previous study by Federmier and Kutas (2001). These researchers found that the N100/P100 was sensitive to semantic expectancy violations in a picture processing task using sentence final line drawings. Other studies have found that the N100/P100 is primarily sensitive to early visual discrimination (Schendan, Ganis, & Kutas, 1998). Because differences in visual similarity between the two conditions were not controlled in our study, it is possible that the processing differences at this early point reflect early visual processing differences between the two conditions. Thus both explanations of this effect are consistent with our data. Furthermore, the skill interaction at this time point could, in principle also be consistent with either a visual processing difference or a semantic processing difference. More research, with stimuli that are controlled for visual overlap, comparing skilled differences in picture processing would help to clarify the interpretation of this component.

4.2.3. Phonological task

In the ERP data**,** there were several components that were found to be sensitive to the homophone manipulation (sound-alike vs. not alike). First, there was a large N400 effect that was more negative for non-homophonic targets than for homophonic targets. Similar effects have been found in several other studies involving rhyme judgment tasks (in English, Kramer and Donchin, 1987; and in non-English languages, Valdes Sosa, Gonzalez, Liu, & Zhang, 1993). The N400 to picture stimuli is considered part of the same class of effects as the semantic N400, which is sensitive to multiple types of relationship violations. Additionally, there was a MFN elicited by the phonological task, which was more anterior than the N400 and somewhat shorter in duration. The MFN, like the N400 has been demonstrated in semantic tasks, but it has not been seen previously (to our knowledge) in phonological processing tasks. Our findings suggest that like the N400 the MFN may be sensitive to a range of tasks, where attention is directed to detecting matches and mismatches.

As in the semantic word task, targets in the phonological task also elicited a negative going waveform at 200 ms that was more negative for non-homophonic targets than for homophonic targets. This N200 component mirrored the divergence between related and unrelated words in the semantic-words task, but was not present in the picture task, which implies that this component may be involved in early mismatch detection for word stimuli. It is unclear in our study whether the differences for relatedness conditions elicited in this component are due entirely to phonological processing or also reflect orthographic differences, as homophone pairs were somewhat more similar orthographically than phonological pairs, although not significantly p>.1 (Appendix A). Similar N200 responses have been found in both rhyme judgment and orthographic judgment tasks (Kramer & Donchin, 1987; Barnea & Breznitz, 1998). Importantly, as in the N400 and MFN findings, the critical interactions between this component and skill were not significant.

It is interesting, given the behavioral processing differences between skilled and less skilled comprehenders on the phonological task, that none of the elicited ERP components in the phonological task were sensitive to skill differences. In the behavioral data less-skilled comprehenders were slower to make the sound-alike judgments than skilled comprehenders, which suggested either a phonological processing difference between the two groups[16]. The difference between ERP sensitivity to skill differences in phonological processing and behavioral differences in phonological processing suggests that less-skilled comprehenders may differ in processing speed at later decision making stage which would be reflected in behavioral data but not necessarily in ERP components. However, another possibility is that less-skilled comprehenders' waveforms do differ during phonological processing tasks, but not in any of the components we tested. For example, the overall shape of the waveforms, in all tasks differed

[16] Whether the difference is due to early processing differences or later decision making differences cannot be determined from behavioral data.

between skill groups. In particular the skilled comprehenders tended to have greater positive deflection overall, regardless of manipulation, and the less skill-comprehenders tended have more negative deflection. This difference can be seen in all of the topoplots for all of the tasks, but is particularly noticeable in the phonological task waveforms. For Example, looking at the CZ electrode in the phonological task across skill groups (Figures 4.11 & 4.12) reveals that the negative most part of the waveform is around -1uv and the positive most part is around 5 uv compared with skilled-comprehenders, whose negative most part is around 2.5 uv and the positive most part is around 8 uv. It is difficult to interpret this finding due to the poverty of work done with ERP comparing skilled and less-skilled readers. However, it is possible that this general difference polarity could reflect an underlying processing difference. Close examination of figures from two other ERP studies that examined reading skill differences (although not limited to comprehension differences per se), revealed that less-skilled readers and had generally more negative waveforms, however, neither group commented on this difference in the manuscript (Perfetti, Wlotko, & Hart (submitted); Segalowitz et al, 1992). This cursory examination suggests that this polarity difference may be real, and that it deserves further investigation. Unfortunately, because negativity and positivity at a particular point on the scalp are determined by a number of factors that determine current flow including, neuronal orientation and whether the neurons are being excited or inhibited (see Kutas & Van Petten, 1994) it is impossible to speculate about why this general difference in polarity between the two skill groups occurs without additional research.

4.2.4. Conclusions

In conclusion, In the ERP data, we found several components that were sensitive to different types of semantic relationships (related vs. unrelated and categorical vs. associative). This was true for ERP responses between 300 ms and 600 ms in central and parietal regions (N400) between 300 ms and 500 ms in frontal regions (MFN) between 150 ms and 250 ms in frontal and central regions (N200). As far as we know, this is the first data to demonstrate neurophysiological sensitivity to differences between categorical and associative relationships.

Furthermore, the elicited differences in ERP waveforms between less-skilled and skilled comprehenders during semantic tasks, particularly the semantic-words task, suggest an underlying semantic processing difference between these two groups of readers. Both the N400 and N200 were sensitive to semantic relatedness differences as well as comprehension skill differences. The lack of late component differences in the semantic-pictures task suggests that difference in semantic processing between skilled and less-skilled comprehenders are primarily limited to the linguistic-semantic domain.

We failed to find differences in ERP components elicited for skilled and less-skilled comprehenders during the phonological task, which suggest that these readers do not differ in their phonological processing ability. This finding is consistent with the fact that these groups did not differ on the behavioral elision task they were given during the screening battery. However, this lack of difference must be interpreted cautiously as skill groups did differ in behavioral reaction time, suggesting a phonological processing difference further downstream.

5. CHAPTER 5

5.1. RESULTS SUMMARY

In Chapter 2, examination of a large database of adult readers demonstrated that less-skilled comprehenders who had adequate decoding abilities were as frequent in the adult population as they are in the children's population. A PCA found that certain abilities shared more variance with Comprehension than other abilities. More specifically, vocabulary ART and comprehension shared more common variance than did decoding or spelling tasks with Vocabulary, ART or comprehension. Moreover, Decoding and Spelling shared more variance with each other than any of the other three tasks. These findings suggest a partial dissociation between low–level orthographic/phonological skills and higher-level skills. In Experiments 2, 3 and 4 adults had significantly different comprehension scores but similar scores on a measure of speeded non-word reading (as assessed by the TOWRE) and on measures of spelling, decoding and phonological awareness, again suggesting a dissociation between higher level and lower level reading skills. However, the findings from our regression analyses in Chapter 3 indicate that even tasks that clustered together in the PCA correlate differently with certain semantic tasks. In particular, Vocabulary was correlated more strongly with word-level semantic tasks and Comprehension correlated more strongly with categorical semantic tasks. Thus, there was a partial dissociation between "higher-level" and "lower-level" skills but the size of the dissociation seems to vary with task (and is larger or smaller for different high compared with low level skills).

In Chapter 3 we compared skilled and less-skilled comprehenders (matched for decoding ability and IQ) on two tasks that tapped semantic knowledge, verbal fluency and semantic priming. The results from our verbal fluency task suggested differences in semantic processing between skilled and less-skilled comprehenders by demonstrating differences in the number of associates generated to a category label (animals). Regression analyses found that comprehension skill was the primary predictor of categorical associate generation. However, these findings were statistically weak and several follow up comparisons on the type (imageability, semantic clustering and frequency) of responses given by skilled and less-skilled comprehenders failed to yield significant differences.

Our second behavioral experiment examined automatic semantic priming in skilled and less skilled comprehenders (matched for decoding and IQ). We compared both associative priming and categorical priming and found that less-skilled comprehenders showed similar amounts of associative priming but failed to show categorical priming. This finding was consistent with a previous study that found associative but not categorical priming in young children (Nation & Snowling, 1998). A series of follow up regressions reinforced the results by showing strong correlations between comprehension and categorical priming but not between comprehension skill and associative priming. These findings indicate that less-skilled comprehenders do differ from skilled comprehenders in semantic processing ability and in particular they differ in processing categorical relationships. Although these skill differences were larger than the skill differences in the VF study, the interaction between skill and type of priming was only marginal, and thus provide only suggestive evidence for semantic deficits in less-skilled comprehenders.

Chapter 4 used a direct online measure of neural processing to compare skilled and less-skilled comprehenders on a semantic processing task. Three different ERP tasks measured processing of semantic relationships between words, semantic relationships between pictures and phonological processing of words. The ERP records revealed that several components were sensitive to semantic processing. The earliest component was detected at 100 ms and was sensitive to semantic picture processing. This N100/P100 was more negative in anterior regions for semantically unrelated pictures than for semantically related pictures. Another component that peaked around 200 ms was sensitive to semantic word processing and phonological processing. This component was more negative in anterior regions for semantically related items (both associative and categorically related targets) than for semantically unrelated words. Also, it distinguished between categorical and associative relationships, the waveform was more negative for categorically related than for associatively related pairs. In the phonological task, non-homophonic (sound different) targets were more negative at this time point in anterior regions than homophone (sound same) targets. These findings suggested that this component was sensitive to stimulus mismatch, regardless of type of mismatch. Two later components were also sensitive to semantic and phonological processing. An anterior negative waveform that began around 300 ms and continued until around 500 ms identified as the MFN was more negative for "mismatches" than for matches in all tasks. In the semantic word task the unrelated targets produced the most negative going waveform, the categorically related targets were more positive (MFN reduction) and the associatively related targets were even more positive (greater MFN reduction). In the picture semantic task, related pictures were more positive than unrelated pictures; and in the phonological task homophone targets were more positive than non-homophonic targets.

The latest component identified was the N400; a classic finding of increased negativity between 300 ms and 600 ms for stimulus mismatches. In our data a large N400 was identified in each of the three tasks. Like the MFN, the N400 component was more negative for unrelated relative to categorically related or associatively related words, and more negative for categorically related words than for associatively related words in the semantic word task. In the semantic picture task the N400 was more negative for semantically unrelated pictures relative to semantically related pictures. And in the phonological task the N400 was more negative for non-homophones than for homophones.

Importantly several of these components were sensitive to comprehension skill differences in the semantic word task. The N200 reductions for categorically related and for associatively related items were non-significant for less-skilled comprehenders but significant for skilled-comprehenders, suggesting relatively early differences in semantic processing. Furthermore, the N400 reductions for categorically related and for associatively related items were smaller (although significant) for less-skilled comprehenders. Additionally, in both components, less-skilled comprehenders' waveforms did not differ significantly for categorical compared with associatively related pairs, whereas skilled comprehenders' waveforms did. Taken together, these findings indicate semantic processing differences between skilled and less skilled comprehenders for both categorical and associative relationships. Differences between the categorical and associative relationships emerged in the ERP data but not in the behavioral data for several possible reasons. First, ERP measures neural response directly thus, it is likely to be more sensitive to subtle differences such as greater sensitivity to associative relationships in skilled readers. Second, in addition to getting a longer amount of time for processing in the ERP task, the task demands required overt processing of semantic relationships; whereas the priming task (given the short SOA and response deadline) measured automatic semantic processing. Interestingly, there were only small skill differences in the semantic-picture task suggesting that the processing differences between the two skill groups was limited primarily to processing of linguistic information.

In the phonological task, the skilled readers did not show any skill differences in their ERP waveforms for any of the components, suggesting a lack of phonological processing differences between the groups. However, the two groups did differ in their reaction times during the phonological task. This difference could be attributable to the fact that the groups differ with respect to later, decision making processing in phonological tasks. Alternatively, our failure to detect a significant difference in the ERP waveforms, like any null result, could be due a lack of sensitivity in the design. Moreover, less-skilled comprehenders' waveforms were slightly more negative in all of the tasks and that may be reflective of other, more general processing differences that may have cause greater response latencies. Additional research is needed to test this hypothesis.

In general, our findings provide support for the idea that at least two types of poor comprehenders exist in the adult population. Although many less-skilled comprehenders suffer from low level word reading difficulties, some perform normally on tests of decoding and PA. These comprehenders had relatively poor performance on measures of vocabulary and print exposure (as indicated by the results from our PCA and by the significant differences on these tasks between our two groups of readers in Experiments 2 and 3). Furthermore, with sufficiently sensitive measures less-skilled comprehenders also show differences on measures of semantic processing. However, the differences were variable, depending on task demands and measurement tools. More specifically, in behavioral data the differences seemed limited to the processing of categorical relationships, but in the ERP data, differences in both categorical and associative processing emerged.

5.2. Conclusions

5.2.1. What have we learned? Semantic skill underlies comprehension skill

The simple view of reading comprehension is that successful reading comprehension requires facility with listening comprehension and decoding (Gough & Tunmer, 1986). One implication of this view is that reading comprehension failure suggests a problem either with the skills that underlie decoding, or with the skills that underlie listening comprehension, or both. Although this simple view is widely accepted, few studies have considered reading comprehension failure independent of decoding failure. Even studies that tried to focus on comprehension failure have rarely included adequate matching on decoding ability (e.g., reading in context), thus making any conclusions about reading comprehension failure confounded with conclusions about decoding failure. Several studies have made recent advances in our knowledge of comprehension failure by including better low-level reading controls (Oakhill & Cain, 2000; Oakhill, Cain & Bryant, 2003). These studies have reveled that many poor comprehenders have at least adequate decoding skills, despite their poor comprehension skills. Unfortunately, the bulk of these experiments with poor comprehenders have failed to asses possible causal factors and instead have focused on correlations between reading comprehension and other text level processes (such as inference making).

One auspicious line of research has found that children with comprehension difficulties, despite adequate decoding skills and IQ, had weaker semantic skills than children with average or good comprehension skills Nation & Snowling, 1988;1999; Nation et al., 2005).Given its broad implications, a semantic processing deficit provides a plausible explanation of comprehension failure, and the variety of difficulties associated with reading comprehension failure including vocabulary skills, listening comprehension, inference making (to name a few). Although this hypothesis is encouraging, some researchers have called into question whether semantic difficulties in young readers are simply due to delayed semantic development, and not a lasting semantic difference. Furthermore, important questions about nature and origin of the deficit were left unanswered. The results of the experiments discussed in this thesis provide additional evidence for semantic processing differences in less-skilled comprehenders compared with skilled comprehenders (who were matched on decoding ability). Results from a verbal fluency task showed that comprehension skill is predictive of how many semantic associates are generated to category labels and results from a semantic priming task with very short SOA's showed that the processing deficit is apparent even in automatic semantic processing. Furthermore, results from three ERP tasks showed neurophysiological differences in a verbal-semantic task but not in a picture-semantic task or a phonological processing task. These results suggest that semantic deficits in processing are limited to the processing of linguistic-semantic information. Taken together with Nation and Snowling's (1998;1999;Nation et al., 2005) findings of poorer vocabulary, slower exception and low frequency word reading, less categorical priming, and difficulty with irregular past tense production in poor comprehenders, our findings provide evidence that semantic skill is an important underlying factor in reading comprehension skill regardless of age or developmental status.

5.2.2. What is the source of semantic skill differences?

How do less-skilled comprehenders come to have impoverished semantic representations? Are there fundamental differences between individuals' ability to acquire semantic knowledge? Although there are likely to be some innate differences between individuals in both the ability to acquire and the ability to access knowledge, increasing evidence suggests that the primary way in which semantic representations are strengthened is through co-occurrence of information, thus the most likely cause of developmental[17] semantic impairments is a failure to strengthen these representations. That is, less-skilled comprehenders' deficits are most likely to be caused by differences in experience. MacDonald and Christiansen (2002) proposed that a lack of reading experience can appear as impairments in semantic processing. They suggested that representations at the word or concept level are built up over time through multiple encounters with words and concepts (see also McRae et al, 1999 for a similar hypothesis). The idea that semantic representations for objects and words are built up over time through experience is not a new one. Over a hundred years ago Carl Wernicke suggested that the most likely way that humans acquire verbal representations of objects in the world is through simultaneously experiencing things and learning their verbal labels.

[17] Developmental is used here to distinguish these impairments from acquired impairments (usually through injury or disease) not to imply that these impairments apply only to children.

Although this experience-based theory has the potential to explain our findings as well as Nation and Snowling's findings of reduced semantic skills in less-skilled comprehenders, it is difficult to prove or disprove without large scale longitudinal investigations. Despite this lack of direct evidence for the theory, existence proofs have been provided by connectionist models of knowledge development. These models have been built to test the idea that semantic representations are built up through experience. For example, Rogers et al. (2004) have demonstrated that "semantic knowledge emerges from the interactive activation of modality specific perceptual representations of objects and statements about objects" (pg. 2, Rogers et al.). In their model, semantic relationships between objects are not pre-specified, but instead are allowed to emerge as the network learns the associations between perceptual entities and verbal labels. The model is able to simulate many of the difficulties that semantic dementia patients experience by degrading the representations that were built up through experience. For example, the model was able to match the object naming behavior of semantic dementia patients. Both the model with degraded semantic relations (degraded weights) and dementia patients showed increased omission errors (subjects are unable to produce an object name) and superordinate errors (subjects provided a more general name) as the disease or amount of degradation of the model's weights progressed.

Models that operate on similar principles have been proposed to explain the specific effects observed in the word reading of patients or children with semantic impairments. Connectionist models of word reading represent words as triples of orthographic, phonological and semantic information whose interconnections become strengthened as they co-occur (Plaut et al., 1996; Seidenberg & McClelland, 1989; Plaut & Shallice, 1993). These models represent word recognition as activation of a layer of orthographic units that spreads to a group of phonological units and to a layer of semantic units, via a layer of hidden units. The amount of activation that reaches the next layer in the network is dependent on the strength of the weights between units. Higher weights are produced through increased learning experience. Thus, greater experience yields a more reliable mapping between input and output. Because weights are strengthened over time through experience, low frequency and inconsistent words have weaker connections. In this way the model is able to account for frequency and consistency effects in the word reading of normal and semantically impaired individuals. The model can demonstrate surface dyslexic performance (weak irregular performance for both low frequency and high frequency words and exaggerated frequency effects) if its semantic inputs are lesioned or if it is arrested early in development (Plaut & Shallice, 1993). These models provide clear demonstrations that systems built up through experience can exhibit selective semantic impairment in reading via damage (as in semantic dementia patients) or via arresting experience (as in less-skilled comprehenders). We recognize that a theory that posits importance of semantic knowledge for comprehension bears some superficial resemblance to theories of expertise and the relationship between expertise and comprehension. Several studies have found that domain expertise is a good predictor of comprehension of texts within that domain (Chi, 1985; Stanovich & Cunningham, 1993). Connectionist theories, however, go further in that they propose a mechanism by which knowledge is built up and they are able to empirically demonstrate the results of missing or incomplete knowledge.

Viewing semantic processing as critically linked to semantic knowledge that has built up throughout life's experiences makes the connection to comprehension obvious. Without knowledge (or with weak knowledge) of concepts, no new information can be integrated and hence no new information can be understood. However, one very important question remains we still don't know how skilled and less-skilled comprehenders' experiences differed. One possibility is that they don't differ per se, but that less-skilled comprehenders are less sensitive to the statistical relationships between concepts. Thus, these individuals would require more experiences or "higher quality" experience to gain the same amount of knowledge as a skilled comprehender would. Another possibility is that less-skilled comprehenders require the same experiences as skilled comprehenders but have had fewer or impoverished experiences. The fact that in general people's experiences are different is trivially obvious; someone growing up in a highly educated upper middle class family is likely to have "richer" experiences than someone who hasn't had all of the advantages of such a lifestyle. However, our findings and the findings of others (e.g., Nation et al., 2005), demonstrate differences in less-skilled comprehenders' semantic representations in relatively homogenous populations[18] Thus, more subtle differences would have to account for these differences. It is likely that a combination of these inadequacies occurred in our less-skilled comprehenders. Moreover, the relationship between lack of experience, semantic knowledge and comprehension skill is likely to be reciprocal. Fewer high quality experiences lead to impoverished semantic representations which lead to poor comprehension ability, which discourages reading, which furthers the trend for inadequate experiences (as most adults learn new information primarily through reading).

In sum, we have demonstrated that semantic deficits are one underlying cause of comprehension failure in healthy adults. The present studies showed differences in

[18] State University undergrads in our studies and British children from working class homes in the studies by Nation and Snowling (1998; 1999) and Nation et al. (2005).

comprehension and semantic processing that cannot be attributed to differences in decoding skill or to a developmental lag. We speculate that differences in experience give rise to individual differences in semantic processing and comprehension skill.

APPENDIX A

Table 1. Frequencies and associative strengths of words in the priming and ERP semantic-word tasks (Experiments 3 and 4)

	Associatively related pairs	Categorically related pairs	Unrelated pairs
Target/Word 1 frequency	51.5 (92)	52.3 (192)	50 (87)
Prime/Word 2 frequency	60 (119)	54 (237)	69 (67)
EAT Associative strength	0.23 (.2)	0.008 (.003)	--
LSA	0.46	0.33	--

Standard deviations in parentheses

Table 2. Frequencies, target lengths and letter overlap for words in the phonological task (Experiment 4)

	Homophone	Non-homophone
Word 1 frequency	58 (92)	92 (192)
Word 2 frequency	63.1 (119)	104 (237)
Target length	4.37 (0.7)	4.35 (0.7)
Shared letters	3 (0.72)	2.5 (0.88)

Standard deviations in parentheses

APPENDIX B

Table 1. Skill tests means and ANOVA results (Experiment 4)

	Less-skilled	**skilled**	**F value**	**P value**
TOWRE	52.9(6.1)	55.6(5.8)	1.49	.232
ND Comprehension	12.44(4)	24.26(4)	58.61	**.000**
Spelling	.8(.1)	.83(.05)	1.22	.279
PA (elision)	.76(.17)	.83(.11)	2.13	.155
Ravens	7.42(3.11)	8.0(3.4)	0.320	.576
ND Vocabulary	43(14)	58(16)	7.58	**.010**

Standard deviations in parentheses

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