The Effects of Working Memory Span and Transposed Text on Reading Speed and Reading Comprehension

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Abstract

This is a study investigating the differences between High and Low Span Working Memory individuals in both reading speed and reading comprehension between Regular Text and Transposed Text. Using the Reading Span Task (Daneman & Carpenter, 1980), each subject was placed in either the High or Low Span group. Each subject subsequently was presented with regular and transposed texts and their reading speed and reading comprehension were assessed. High Span individuals were expected to outperform their Low Span counterparts in both reading speed and comprehension. The results supported these expectations. Transposed texts were predicted to produce slower reading speed and lower reading comprehension. The results supported these predictions for reading speed but not for reading comprehension.

The Effects of Working Memory Capacity and Transposed Text on Reading Speed and Reading Comprehension

The research on letter transposition dates back to the 1976 unpublished PhD thesis of Graham Rawlinson. This phenomenon was invigorated by an email that spread around the Internet in 2003; it stated the following:

> *Aoccdrnig to a rscheearch at Cmabrigde Uinervtisy, it deosn't mttaer in waht oredr the ltteers in a wrod are, the olny iprmoetnt tihng is taht the frist and lsat ltteer be at the rghit pclae. The rset can be a toatl mses and you can sitll raed it wouthit porbelm. Tihs is bcuseae the huamn mnid deos not raed ervey lteter by istlef, but the wrod as a wlohe.*

While the citation is false, the concept is true, the human mind can read these supposedly “jumbled” letters with astonishing accuracy. Rawlinson’s unpublished PhD thesis was put forward to examine the importance of letter position in human word recognition. This was accomplished by conducting 36 separate experiments, varying the placement of the transposed letters (Davis, 2003). The specifics provided were sparse, but the overall idea was present. Through his research on the importance of letter position Rawlinson generated the idea that middle letter identification was processed mostly independent of position (Rawlinson, 1976). Also found, was that the beginning and ending of words play a significant role in word recognition; and that the middle letters were not based on accuracy, but instead a probability based system (Rawlinson, 1976). While the paper was a sole PhD thesis that was never published, the ideas it put forth have been tested multiple times confirming the hypothesis: humans can read words with the middle letters transposed with relative ease than if the letters at the beginning or ending were transposed (Rayner, White, Johnson, and Liversedge, 2006).

This idea has been thoroughly studied, primarily in masked-priming studies (Chambers, 1979; Perea & Lupker, 2003). These studies have shown that transposed-letter (TL) non-words are more easily confused with their base words if the letters in the middle of the words are transposed more so than letters transposed at the beginnings or endings of words. Meaning that TL non-words close to their base word (e.g., WINDOWS and WIDNOWS) can more easily be confused, and therefore understood, than TL non-words that differ greatly from their base word (e.g., WINDOWS and WDIONSW). Further, Johnson, Perea and Rayner (2007) studied the parafoveal views of words and the effects of TL non-words and Substituted-Letter (SL; e.g., WMIODUS vs. WNIODWS) non-words. The researchers measured the amount of time subject's eyes were focused on the beginning space before the word, the word itself, and the space after each word. They also noted any re-readings of particular words. Their results showed that the TL conditions led to significantly shorter durations than the SL conditions. These results mean that while reading, the individuals spent less time reading over the TL condition non-words than the SL condition non-words; hus suggesting that the subject's coded the words and read them as regular words rather than words with transposed letters. They also found that the results from their first experiment indicate that the TL effects that occur in naming and lexical decision experiments also exist during normal silent reading. Rayner, White, Johnson, and Liversedge (2006) studied differences in reading words-per-minute (wpm) with transposed letters. The results from this study demonstrate that TL's in the middle of words were read significantly faster than TL's at the beginning or ending of words. However, the TL-middle words reading speed was 11% slower than reading regularly typed words (255 Regular vs. 227 TL).

In Andrews (1996), TL non-word reaction times for masked priming were demonstrated to be impaired by TL non-words that are overly similar to other words, or blatantly form other words (e.g., CALM → CLAM). They presented on the screen, a focus (+) for subjects. The then flashed a word, either regularly typed or transposed, and then in its place a mask to hide and residual after-images on the screen. After this they displayed the target word they asked subjects to state.

Perea and Lupker (2004) demonstrated that, in Spanish, this TL prime advantage only exists when the letters transposed are consonants and not vowels. However this was replicated for English by Lupker, Perea, and Davis (2008) later on. They found that there is the same advantage in English for consonants transposed over vowels. However, the frequency of the letter used effects the advantage; more frequently used consonants are perceived to be closer to the base word. The TL effect has also been studied between Hebrew and English. This study wanted to look at the effects of transpositions between English and Hebrew in perfectly 50/50 bilingual individuals. Because of the structure of the Hebrew language, reading words jumbled was expected to be significantly more difficult because the words are based off of their roots. One root can start a large collection of potential words. Their results demonstrated that the TL effect is significantly more difficult in Hebrew sentences and word recognition than in English (Velan & Frost, 2007).

Beyond simply the placement of letters in smaller words, research has been done on compounded words with morpheme boundaries (Christianson, Johnson, & Rayner, 2005). This study looked into the TL effect within compound words. Because compound words are formed between two words whose meanings combine into one word, they proposed that the beginnings and endings of each word in the compound would need to be in place for proper TL effects. For example: in the word *SUNSHINE*, there is a morpheme boundary between *SUN* and *SHINE* that if crossed in transposition, would make it difficult to comprehend quickly. (e.g., *SUNSIHNE* is easier than *SUSNHINE*). Christianson et al., also researched pseudo-compound words (words comprised of two words that do not share a meaning i.e. *mayhem*) and found that they related more to non-compound words in terms of reaction times. This suggests that humans are sensitive to word boundaries, even internally with the TL effect.

Along with the Transposed-Letter effect, the current study examined Working Memory Span (also known as Working Memory Capacity; WMC) on High Span and Low Span individual's reading comprehension and reading speeds. The term *Working Memory* (WM) was developed as a way to refer to a more active part of the processing system in humans. WM has been shown to have processing as well as store functions. It serves as the location for executing processes and storing the information produced in these processes. To give an example, consider reading: "*…in reading comprehension, the reader must store pragmatic, semantic, and syntactic information from the preceding text and use it in disambiguating, parsing, and integrating the subsequent text"* (Daneman & Carpenter, 1980; 1983). That information can be lost from the working memory leads to the assumption that capacity within it is limited. Therefore, individual differences theories state that there are differences in people's abilities to store and process data within their Working Memory. Daneman and Carpenter (1980) developed the Reading Span Task to measure the WMC of individuals while reading. During reading, Daneman and colleagues theorized that people with lower WMC have a smaller capacity which limits the amount of information these individuals can integrate from the text and from prior or background knowledge.

Further research into WMC has shown that it plays a large role in reading comprehension (McVay & Kane, 2012). Faulkner and Levy (1999) studied the ability of fluent and non-fluent readers to process information and how they read. They found that skilled readers do not typically focus on the micro-level information (word-by-word reading, etc.), but instead focus on the macro-level information (context, meaning, etc.). This is reversed for poorly skilled readers who spend so much time on the micro-level information that the subjects may miss the macro-level information. Also found, was that because of this ability of fluent readers to simply process the contextual “macro-level”, they were able to read much more quickly than non-fluent individuals.

This study is investigating the differences between High and Low WM Span individuals in reading transposed text and regular text and answering comprehension questions. Although no previous research has looked at the TL in full paragraph reading and comprehending, the expectation can be inferred from the research on priming and sentence reading. Because of the relationship between reading comprehension, reading speed, and working memory span, it is expected that High Span individuals will outperform their Low Span counterparts in both reading speed and reading comprehension for both transposed text and regularly typed text (Daneman & Carpenter, 1980; Faulkner & Levy, 1999; McVay & Kane, 2012). It is also expected that because of the previously seen slight decrease in reaction and comprehension time (Rayner et al., 2006), transposed text reading times and reading comprehension scores will be significantly lower than those of regularly typed text.

Method

Participants

Twenty-four individuals participated in this research. Participant ages ranged between 18-80 years.

Apparatus and Materials

The Automated Reading Span Task (Daneman and Carpenter, 1980; Unsworth, Heitz, Schrock, and Engle, 2005) was used to collect the initial data of every subject's Working Memory Capacity. The Transposed Paragraph Task was designed and created using E-Prime 1.0 and was converted to E-Prime 2.0 software (Psychology Software Tools, Pittsburgh, PA). Experiment was run between two separate computers due to program limitations. The Reading Span Task was run on Dell PCs equipped with an Intel Celeron Processor, 128 MB of Ram, and Microsoft Windows XP. The Transposed Paragraph Task was run on a Sony Vaio Laptop with an Intel i5 Processor, 8 GB of RAM, and Microsoft Windows 8 Consumer Preview. Testing was completed in the Neuroscience Laboratory at Saint Mary's College of California.

Procedure

The experiment is a 2x2 mixed-factor design. The initial factor separated the participants into two groups: High Working Memory Span or Low Working Memory Span. The second factor was a within subject factor of Transposed Text and Regularly Typed Text (See Appendix A for examples). Each individual was measured on their reading time (in seconds) and the percentage of questions correct between Transposed and Regularly Typed Text. The Working Memory Span was determined using the Reading Span Task.

The participants began the experiment with the Reading Span Task (Daneman & Carpenter, 1980) at the first computer station. Upon confirmation, the run file began the experiment. Participants were given a practice test of recalling letters presented to them in a particular order. After the first practice, participants were given practice of answering true and false to sentences. The participants were then given a combined practice of reading sentences for comprehension, answering true or false to the sentence, and remembering the letters presented afterward. This practice ran 3 full times. Once completed, the data-collecting Reading Span Task was run. The Reading Span Task varied between 3-7 sentence-letter combinations. When the experiment was over, the participants were instructed to inform the experimenter. Once the program was closed, the experimenter guided the participant to another work station to begin the Transposed Paragraph Task. The Transposed Paragraph Task asked individuals to read selected paragraphs and answer reading comprehension questions following each text. Three paragraphs were regularly typed; three were transposed following rules previously described. These were distributed in a varying order: *Regular-Transposed-Regular-Transposed-Regular-Transposed*. None of the reading comprehension questions were transposed. Upon completion of the program, the participants were instructed to inform the experimenter and were thanked for their time.

Results

The Reading Speeds and Reading Comprehension were subjected to an Analysis of Variance (ANOVA) having two levels of Working Memory Span (High or Low) and Two levels of Text Type (Transposed and Regular). All effects were tested at an alpha level of .05.

An analysis for Reading Speed comparing Regular Text reading speed for High Span individuals (M = 368.85, SD = 132.75) and Low Span individuals (M = 515.47, SD = 191.64) against Transposed Text reading speed (M = 316.79, SD = 118.32) and Regular Text reading speed (M = 429.61, SD = 140.24) was conducted and showed a significant main effect for Text Type ($F_{(1,22)} = 11.102$, $p < .05$). Results show that, Regular Text reading speeds for both High Span individuals and Low Span individuals were both significantly faster than Transposed Text reading speeds for both High and Low Span individuals. There was no significant interaction effect ($F_{(1,22)} = .667$, $p > .05$). (See Table 1 and Figure 1).

An analysis for Reading Comprehension comparing Regular Text reading comprehension for High Span individuals (*M* = 83.13, *SD* = 25.42) and Low Span individuals (*M* = 59.94, *SD* = 24.96) against Transposed Text reading comprehension for High Span (*M* = 72.5, *SD* = 31.96) and Low Span (*M* = 45, *SD* = 27.81) individuals was conducted and showed no significant main effect for levels of Text Type ($F_{(1,22)} = 2.712$, $p > .05$). Nor was there any significant interaction effect between Text Type and Working Memory Span ($F_{(1,22)} = .077$, $p = .784$). (See Table 2 and Figure 2).

Discussion

This experiment was designed to analyze the differences between High and Low Span WM individuals in reading speed and reading comprehension, using transposed and regularly typed texts. The Working Memory Span of each individual was determined by using the Reading Span Task. Reading speed and reading comprehension were determined by having all subjects read three regularly typed paragraphs and three transposed paragraphs (answering questions after each text). The results provided both expected and unexpected data.

According to the data, the High Span individual's mean reading times were faster than those of the Low Span individuals for both regularly typed and transposed text. This follows with what was expected as High Span individuals are able to process and store more information overall compared to the Low Span individuals. It is interesting in looking at the means however, because High Span individuals were only ~ 50 seconds different between regularly typed text and transposed text; showing that they were truly not heavily affected by the transposition of the text. However, the mean reading speeds for transposed texts were overall faster than the reading speeds for regularly typed texts (despite there being no significance). This contradicts what was expected because in previous research, while the TL non-words were close to the base words in terms of reaction time, they were consistently slower. Likewise, Rayner et al., (2006) demonstrated that the words-per-minute for TL non-words was close to the base word times, but were overall 11% slower. The fact that the mean reading speed for both High and Low Span individuals both demonstrated this trend calls the texts themselves into question.

The scores for reading comprehension follow the similar pattern of High Span individuals outperforming their Low Span counterparts. This further supports the assumption that High Span individuals are able to store and process more information, not simply per sentence or slide, but for the overall text/story provided. Overall, there was a significant main effect for reading comprehension between regular text and transposed text. As was expected, the scores for the regularly typed texts were answered more accurately than those of the transposed text. This continues that although the scores were close overall, the regularly typed texts were different enough to be significant.

To investigate the unexpected results gathered for reading speed, further analyses were conducted on the texts used. Due to formatting issues, the regularly typed texts had to be split into two slides more than the transposed texts (9–to-7). After conducting a word count on the total paragraphs for each set (regular and transposed) it was found that the regularly typed texts contained an extra 228 words. While these texts appeared equal in overall length, the discovery of this confound has provided a possible answer as to the questionable results. Particularly, there was a rather short text in the transposed list (253 words) that shortened the speeds overall. Likewise, there happened to be a paragraph in the regularly typed list that was longer than average (502 words, mean = 361 words). The impact of these two texts might explain the extra time that was spent reading the regularly typed text.

To continue research in this area, it is prudent that standardization is reached with the texts, both in terms of length (in words) but also overall difficulty. Due to the exploratory nature of this research, it was unclear as to how subjects would react with the Transposed Paragraph Task. After a few post-experiment interviews, subjects felt that the practice given to them with the Reading Span Task helped prepare them for what followed, however they did not receive this for the Transposed Paragraph Task. Therefore it seems logical, due to the nature of the subjects that comprise the text, to provide a practice for the TPT, both in the regularly typed text and the transposed text.

Appendix A

Transposed Text:

"You apepar to be astnoished," Sherlock siad, simling at my exrpession of suprrise. "Now taht I do konw it I sahll do my bset to fogret it."

Regularly Typed Text:

When we survey our lives and endeavors, we soon observe that almost the whole of our actions and desires is bound up with the existence of other human beings.

Table 1 – Reading Speed

Working Memory Span	Text Type	Mean (in seconds)	Standard Deviation
High Span	*Regular*	368.85	132.75
	Transposed	316.79	118.33
Low Span	*Regular*	515.47	191.64
	Transposed	429.61	140.24

Note: Means all measured in seconds. Regular = Regularly Typed Text, Transposed = Transposed Typed Text.

Table 2 – Reading Comprehension

Working Memory Span	**Text Type**	**Mean (percentage correct)**	**Standard Deviation**
High Span	*Regular*	83.13%	25.42
	Transposed	72.50%	31.96
Low Span	*Regular*	59.94%	24.96
	Transposed	45.00%	27.81

Note: All means in percentages (%). Regular = Regularly Typed Text, Transposed = Transposed Typed Text

Figure 1 – Reading Speed

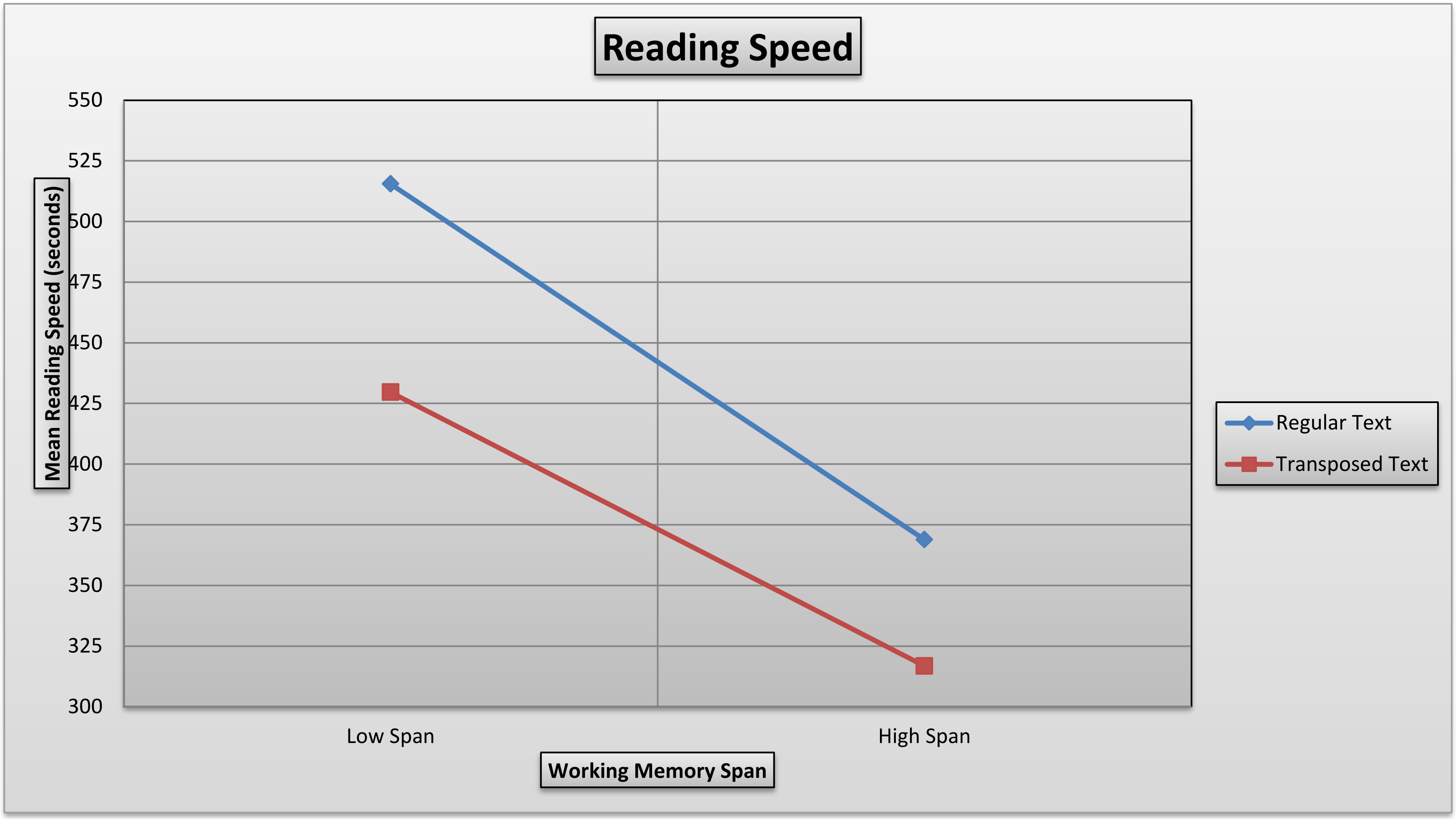
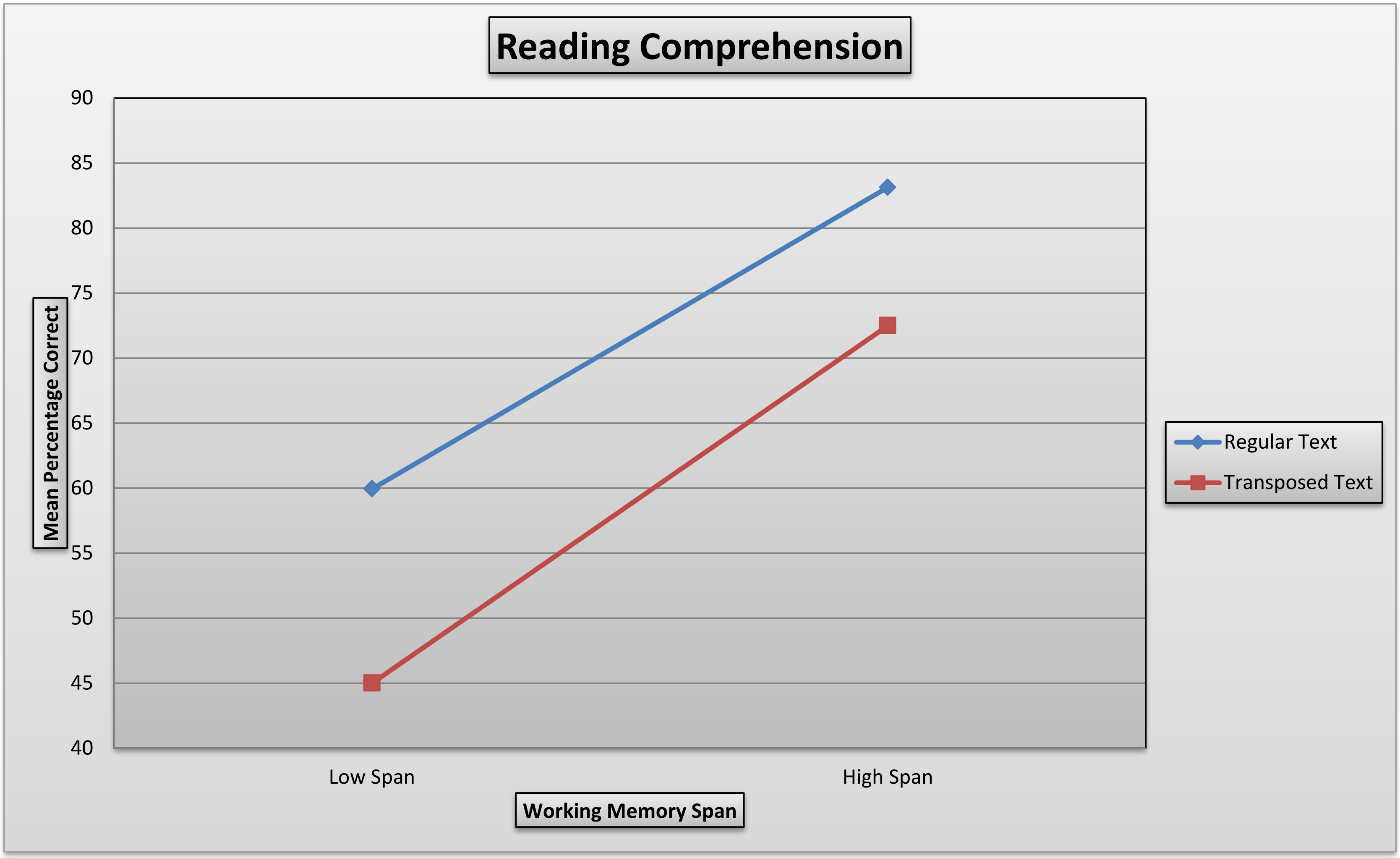


Figure 2 – Reading Comprehension



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Acknowledgements

I would like to thank my mentor and professor Dr. Hoang Vu for his help in the designing and editing of my experiment. I would also like to thank the Saint Mary’s College of California Summer Research Program, for without them I would not have been able to conduct this research. This research was funded by the Summer Research Grant.