Providing Syntactic Part-of-Speech Information Early Speeds-Up Reading

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Reading is a complex task involving the integration of many different sources of information ranging from visual to discourse-level. When those sources of information are used has implications for the architecture of the language processing system. To explore the flexibility of the language processing system, subjects were asked to read sentences in which color cues provided information about words' syntactic part-of-speech. Having the color cues present sped-up reading, which suggests the language processing system is able to make use of information as it becomes available even if it is made available before it would normally be so.

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PREFACE

I would like to thank my advisors, Dr. Tessa Warren and Dr. Erik Reichle without whom this document would not be half of what it is. They provided feedback and support every step of the way and for that I am eternally grateful. I would also like to thank my two research assistants, Hetal Kharecha and Alex Mosby, as well as the other members of the lab including, but not limited to, Patryk Laurent, Francisco Morales, Amanda Virbitsky, and Polina Vanyukov.

1.0 INTRODUCTION

Readers must integrate a variety of sources of information during reading. These sources range from low-level visual information to higher-level discourse information. Although there is consensus that readers make use of these different types of information, an interesting question is *when* these different sources of information are utilized by the sentence processing mechanism. This experiment addresses that question by using the novel approach of manipulating when a certain kind of syntactic information is available. To do this, participants read sentences in which the color of the font indicated a word's part-of-speech, with the logic being that, if the sentence-processing mechanism is flexible enough, it will use the part-of-speech information to identify words more rapidly, increasing the overall reading rate. This pattern of results would suggest that the order in which information is utilized by the sentence processing mechanism is tied to the order in which that information becomes available and is not pre-determined by the architecture of the system. Theories of language processing vary greatly in the posited autonomy and time-course of syntactic processing ranging from modular (Fodor, 1983; Frazier 1978, 1987; Friederici, 2002) to more interactive (Marslen-Wilson & Tyler, 1980; MacDonald, Pearlmutter & Seidenberg, 1994; Hagoort, 2003). The current experiment is intended to shed light on this debate.

1.1 AVAILABILITY OF INFORMATION

Visual, lexical, and linguistic information become available along different timelines during reading. Figure 1 is an abstract representation of when different kinds of information are available to the reader. In the figure, attention has just shifted to the word “fox’. Visual information is represented at the bottom of the figure. Lexical, syntactic, and discourse information are represented above. For the lexical, syntactic, and discourse categories the availability of information is represented by the presence of a dark dot. This dot is not meant to represent the completion of processing, but simply that the information is available.

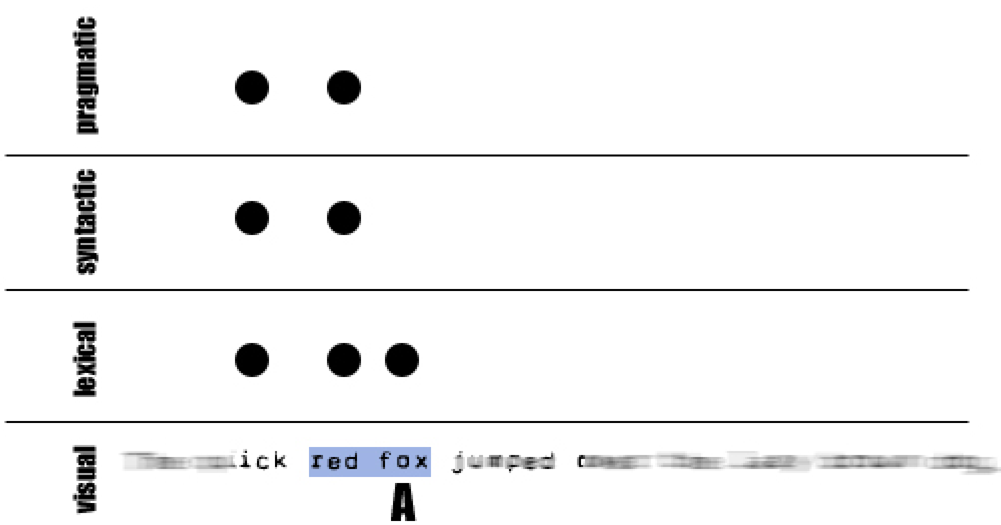

Figure 1

The availability of visual information is represented in the figure by the blurring of words on either side of a “window” where characters are clearly visible. The segment of text around where attention (indicated by a large “A”) is currently located contains the highest level of detail.

This segment represents a physical constraint imposed by the architecture of the human eye and the area of the text which falls on the fovea. Only the fovea, which is an area located in the central 2° region of the retina, has the ability to distinguish the level of detail necessary for reading. Surrounding the fovea are the parafovea and periphery, which are areas of less visual acuity. In Figure 1, text which falls on the parafovea is blurred, but spaces are left intact. Text which falls in the periphery is blurred more completely. Eye movement studies show that readers seem to make use of information from a region defined by word boundaries to the left of fixation (Rayner, Well, & Pollatsek, 1980) and a number of letters to the right (Rayner, Well, Pollatsek, & Bertera, 1982) at least in alphabetic languages like English. This region is referred to as the perceptual span and it extends approximately 3 characters to the left and 14 to the right (see Rayner, 1998 for a review of relevant studies). Within this window, information about the presence of spaces (and word length) is available, however, letter identification is only possible within a smaller window of 7-8 character spaces (Rayner, 1998). Aspects of words such as their length and distance from the reader's current fixation affect their processing time; for example, shorter words tend to be fixated for less time than longer words (Rayner, 1998). Word length (signaled by the presence of spaces) also seems to influence where the eyes move. Readers tend to fixate between the beginning and center of a word, near the optimal viewing location or, the center of a word, where the word can be identified the most rapidly (Rayner, 1998).

Above the visual category of information in the figure is lexical, or word level, information. This arrangement in the figure is meant to indicate that lexical processing can only proceed after visual information has been made available. While this is not indicated in the figure, the lexical information can be further divided into three subcategories: orthography, phonology, and semantics. A word's orthography is its spelling. Detailed orthographic information appears to be available for the first three characters of the word to the right of fixation (Rayner et al., 1982). This information may influence processing of the currently fixated word (Hyona & Bertram, 2004). Orthography is not the same as visual information about letters. This was demonstrated by a study in which the capitalization of alternating letters was alternated (e.g. LiKe ThIs) saccades. Readers did not notice the change and reading behavior did not differ significantly from a control condition where the capitalization remained constant (McConkie & Zola, 1979; Rayner, McConkie, & Zola, 1980). Phonological information is information about a word's pronunciation. Similar to orthographic information, phonological information appears to be available for the word to the right of fixation (Pollatsek, Lesch, Morris, & Rayner, 1992). Finally, a word's semantics, or meaning, does not appear to be available parafoveally (Rayner, Balota, & Pollatsek, 1986; Rayner & Morris, 1992; Pollatsek, Lesch, Morris, & Rayner, 1992; Altarriba, Kambe, Pollatsek, & Rayner, 2001 cf. Vitu, Brysbaert, & Lancelin, 2004; Inhoff, Briihl, & Start, 1998; Murray, 1998; Murray & Rowan, 1998). It also does not affect the processing time of the currently fixated word (Rayner, Balota, & Pollatsek, 1986), nor does it appear to affect where the next word is fixated (Rayner & Morris, 1992). For this reason, no dot appears for lexical information above the word "jumped" which is to the right of the current focus of attention. One hypothesis about the time course of the availability of orthographic, phonological, and semantic information suggests that lexical processing proceeds one word at a time (Reichle, Pollatsek, & Rayner, 2006; Reichle & Laurent, 2006; Reichle, Rayner, & Pollatsek, 1999, 2004; Reichle, Pollatsek, Fisher, & Rayner, 1998; c.f. Inhoff, Eiter, & Radach, 2005; Inhoff, Starr, & Shindler, 2000; Engbert, Nuthmann, Richter, & Kliegl, 2005; Engbert, Longtin, & Kliegl, 2002; Reilly & Radach, 2003; Reilly, 1993). This hypothesis of serial lexical processing is consistent with results from the attention literature, which suggests that the processing necessary to “bind” features of an object to be identified (i.e. a word) requires the serial allocation of attention (Treisman & Gelade, 1980). This is in contrast to visual processing, which appears to take place over a “window” which may encompass several words and which appears to be pre-attentive.

The next category of information represented in Figure 1 is syntactic information. Syntactic information builds upon lexical information because it structurally combines individual words and relates them to the rest of the sentence. In the figure, there is no dot in the syntactic information category above the word “fox” (where attention has just shifted) because it is assumed that some lexical processing (such as recognition of morphology) must be complete before syntactic information can become available (Hahne & Jescheniak, 2001; Munte, Matzke, & Johannes, 1997). Syntactic variables like a word’s part of speech and its position in the sentence affect how difficult it is to incorporate with the other words in the sentence (e.g. Frazier & Clifton, 1989). For example, garden path sentences, which contain temporary ambiguities whose preferred resolution would result in a syntactic violation (e.g. see Frazier & Rayner, 1982), typically cause disruption in late eye movement measures like the probability of making regressions and/or refixations. Although such a result is consistent with a hypothesis of late syntactic processing, a study by Sturt (2003) found that whether or not the gender of a referring expression matched a stereotype (e.g. herself in reference to surgeon) had an effect on early eye movement measures, such as first fixation and gaze duration. (First fixation is the duration of the first fixation on a word during the first pass; gaze duration is the total duration of all fixations on a word during the first pass.) The fact that the two examples just discussed show different time courses suggests that the time course for syntactic information may vary depending on the type of syntactic information being used.

The final category of information represented in Figure 1 is the discourse model. Like syntax, the discourse model also relates individual words to the sentence (or text) as a whole. The discourse model includes information about what has already appeared in the preceding text, as well as other information a reader has available while reading a text like world knowledge. This can involve things like scripts or schema (Bransford & Johnson, 1972) and well-known facts (Hagoort, Hald, Bastiaansen, & Petersson, 2004). Research on the effects of combinatorial semantic information and world knowledge on eye movement has shown early effects in first fixation and gaze duration, as well as later effects on measures like regressions (Warren & McConnell, in press). For example, if a word makes the event described in the sentence impossible, the eye movement record shows very early disruption, lengthening the gaze duration on that word. However, if that same word makes a sentence highly implausible, but not impossible, then the disruption in the eye-movement record shows up in later measures, such as go-past and total time (Warren & McConnell, in press). (Go-past duration is the total amount of time spent between entering a word from the left and before leaving it to the right, including all time spent regressing to the left of the word; total time is the total duration of all fixations on a word.) Moreover, using a paragraph to set up either a normal or “magical” context (e.g. Harry Potter) before an impossible sentence does not change how early the disruption appears in the eye-movement record (Warren, McConnell, & Rayner, 2007; see Rayner, Warren, Juhasz, and Liversedge, 2004 for a review of some additional relevant studies). In Figure 1, the discourse model has not yet been updated for the word “fox” because, like syntactic information, the lexical semantics must be available before a word can be related to the preceding text or a reader’s previous knowledge.

Although the different categories of information mentioned above are discussed separately and sequentially, that is not necessarily meant to suggest that these sources of information are processed in a completely serial or modular manner by the sentence processing mechanism. Instead, it is meant to suggest out that certain lexical information, such as the meaning of a verb, would reasonably be available to the parser before syntactic information, such as the number of arguments that a verb takes. Similarly, information about the discourse model, such as the truth value of a statement, depends on at least the lexical information about the current word. This would suggest that the discourse model is typically only updated after some lexical processing of a word has been completed.

To examine the time course of processing more carefully, the current study is designed to change the timeline over which different kinds of information can become available during natural reading. Specifically, syntactic information about a word's part of speech will be made available before that word is fixated. This information about syntactic categories will be made available in the periphery via the use of color cues. Although normally a word's part-of-speech would not be available until visual processing and some lexical processing had been completed, the color cues will be available in the parafovea, making part-of-speech information available sooner than usual. By manipulating when this syntactic information about a word is available, we will effectively change the *predictability* of that word.

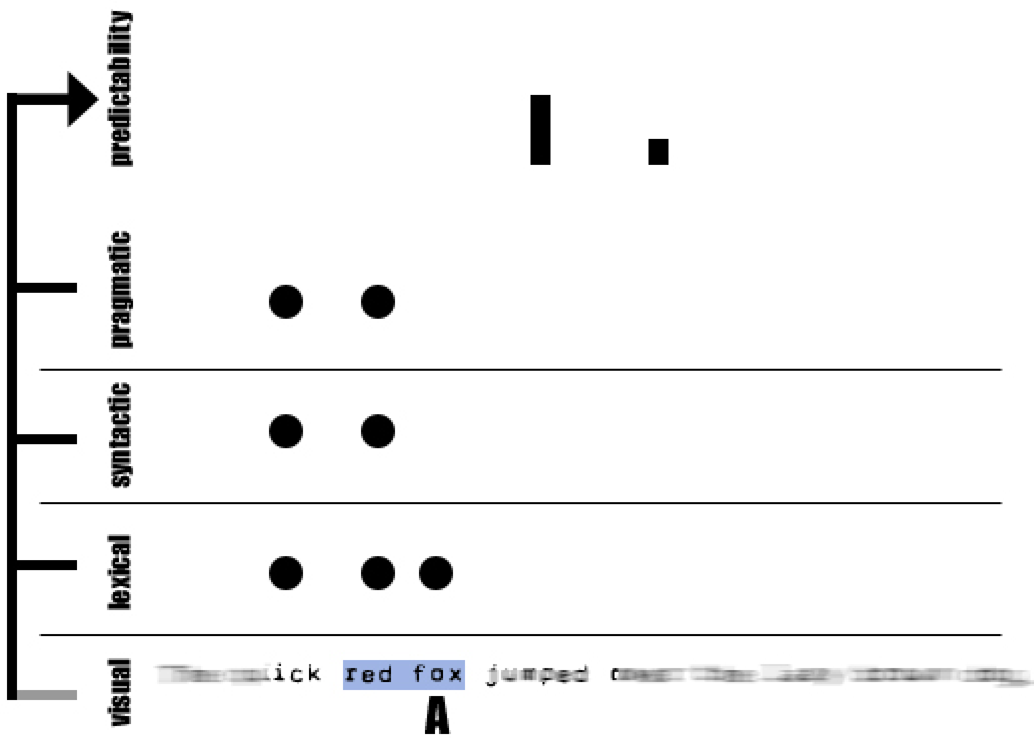

Figure 2

Predictability is a kind of information which has often been operationalized experimentally, but which may or may not correspond to one or more kinds of information computed or used by the human sentence-processing mechanism. Predictability is represented in Figure 2. Experimentally, the predictability of a word is determined through the use of cloze task norms where participants are asked to complete sentence fragments. The proportion of times that participants use a word to complete a particular sentence fragment is defined as the "predictability" of that word. The predictability category in Figure 2 is represented by the bars at the top of the figure. The height of bar is meant to represent the degree of predictability of an upcoming word. However the absence of a scale is deliberate and the size of the bars is meant to be taken as a relative measure, not a quantitative representation of predictability. For example, the bar over the verb "jumped" is relatively large because a verb is likely to follow the end of the noun phrase "the quick red fox". In a cloze task, participants' responses are based on all relevant information provided up until the current word, making this kind of predictability a composite measure which includes information from all of the previously discussed levels of information. This is represented in the figure by the arrows from the visual, lexical, syntactic and discourse categories of information to the predictability category. Unlike those other kinds of information, however, the predictability of a word isn't a variable which is computed using the current word; it is computed in the absence of the current word using all previous words, and it is used to predict how an unidentified upcoming word will be processed.

Predictability has been shown to be a good predictor of reading times using many different methodologies. Words which are more predictable in a given sentence context are read more quickly than words which are less predictable, even when controlling for lexical variables (Erlich & Rayner, 1983; Kliegl, Grabner, Rolfs, & Engbert, 2004; Rayner, Ashby, Pollatsek, & Reichle, 2004; Frisson, Rayner, & Pickering, 2005). Moreover, Frisson et al. (2005) showed that predictability effects could not be explained by the transitional probabilities between individual lexical items. This result is important because, if the effect of predictability could be explained by examining how many times one word follows another word, then it would be explainable as a lexical-level effect.

The current study uses a syntactic manipulation to increase the predictability of upcoming words by providing a color cue that, in one condition, is consistently associated with a word's part-of-speech. This manipulation is hypothesized to affect the time course over which that information then becomes available to the reader. However, to make more precise predictions about how changing the time course will affect reading behavior, it is important to first look at studies of syntactic prediction under normal reading conditions.

One study which looked at syntactic predictability showed that carrying unfulfilled syntactic expectations, such as a verb to complete a sentence, slows the speed at which intervening information is read (Chen, Gibson, & Wolf, 2005). In the same vein, another study demonstrated that the ditransitivity score of a verb (i.e., a measure of how often participants predicted two arguments in a norming study) correlated with longer reading times on the first argument following the verb (Warren & McConnell, 2006). Both of these studies suggest that maintaining predictions is costly for the parser. However, if that cost did not result in any future benefit, then it would make little sense for the parser to make such an effort. In support of this, a study of the "either… or" construction revealed an advantage to making syntactic predictions. Material following "or" was read more quickly when the word "either" was present earlier in the sentence (Staub & Clifton, 2006). This suggests that the cost of generating predictions about upcoming words is in fact advantageous, and that global benefits may be worth local costs.

Another experimental paradigm which may also change the time course of when information is made available to the reader is the "visual world" paradigm. In this paradigm, subjects sometimes receive information from a visual scene which makes a normally ambiguous auditory stream unambiguous. In these experiments, the visual "context" is often provided ahead of time and subjects are asked to listen to auditory stimuli while manipulating a visual scene, although sometimes they are only asked to passively view a visual scene while listening to stimuli. Whereas in text contextual information may hinge on a late-arriving disambiguating word or phrase, in the visual world paradigm the visual scene can serve to provide immediate disambiguation.

Visual world experiments have suggested that when information is provided to the sentence-processing mechanism along a different time course than during normal reading, the reader can make use of that information. For example, in an early visual world experiment, Tanenhaus, Spivey-Knowlton, Eberhard, and Sedivy (1995) showed that the contents of a visual scene could influence adult comprehenders' parsing preferences. The information in the visual scene served as contextual information which boosted the predictability of a certain (less-preferred) syntactic structure. This syntactic structure would have been temporarily ambiguous in a written text, but in the visual world paradigm, a component of the visual scene made it clear that a phrase could (and probably should) be interpreted in the less-preferred way.

The current experiment is designed to examine the flexibility of the sentence-processing mechanism. This flexibility will be tested by changing the time course of the availability of part-of-speech information. Participants will be asked to read sentences where certain words are marked using a color code corresponding to their part of speech. (Color is used as a cue because of its availability in the parafovea; for a visual search example of this, see Fiorentini, 1989.) Based on the results of both the Staub and Clifton (2006) and Tanenhaus et al. (1995) studies, I hypothesize that providing syntactic information earlier than normal will result in a general speed-up of reading. This hypothesis is based on the fact that Staub and Clifton (2006) showed that fulfilling a syntactic prediction results in a speed-up of processing under normal conditions, and because the results of Tanenhaus et al. (1995) suggest that the parser is flexible enough to make use of information provided along a different time course than usual.

1.2 PREDICTIONS

However, it is important to acknowledge that providing syntactic information earlier than it would normally be available could have one of three different effects: Either reading will speed up, slow down, or there will be no change. To discuss each of these predictions, I will refer to Figure 3, which is a modification of the previous figures.

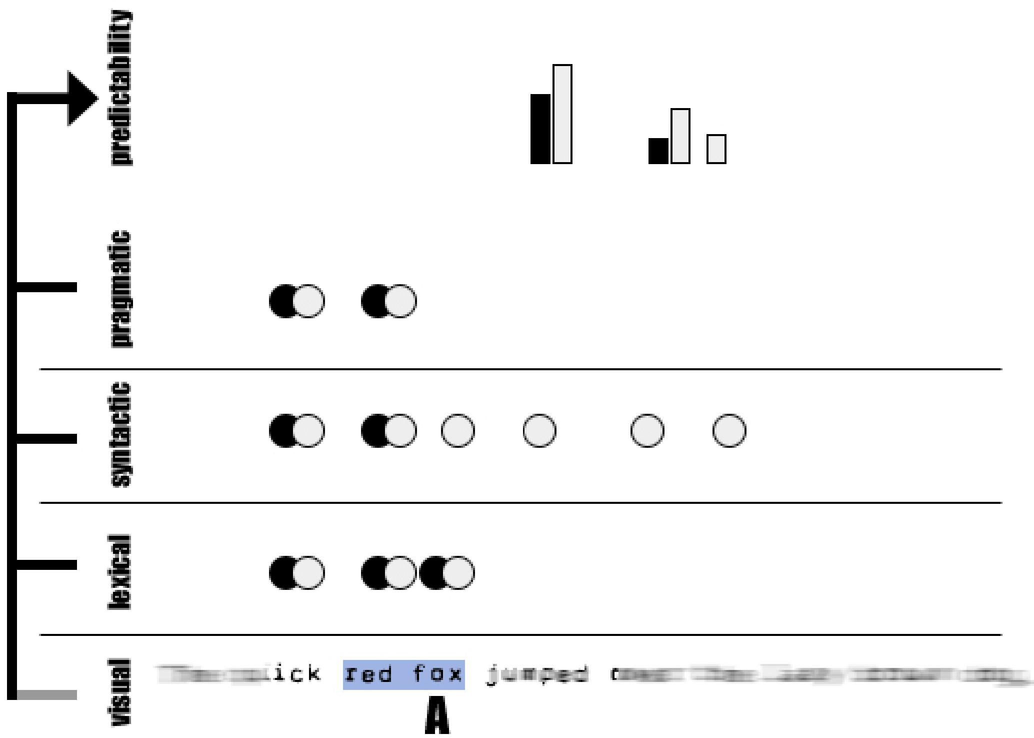

Figure 3

If, as hypothesized, a general speed up is observed, then it could be because the language processor is flexible enough to use the syntactic information early. For example, the syntactic information could restrict the possibilities for the upcoming words and thus reduce the amount of lexical processing that would have to be done. As shown in Figure 3, making the syntactic information available for a future word (the dots in light represent the experimental condition and the dots in dark normal reading conditions) may boost the predictability of those words.

In contrast, if a general slow down is observed, then it could be because the normal automaticity of the language processor is interrupted. For example, if the predictability of a large number of upcoming words is boosted by the availability of their part-of-speech information, then the sentence processor might begin to have trouble maintaining word order.

This possible outcome is represented in the figure by assuming that the greater predictability of multiple words causes them to compete with one another for attention. This might happen because of a shift from serial to parallel lexical processing, so that additional wording memory resources are required to maintain word order. This would cause difficulty (and slowing) because even in languages such as Finnish, which has flexible word order, there is a preferred structure for which processing is facilitated (Hyona & Hujanen, 1997; Kaiser & Trueswell, 2004). Thus, having the syntactic information early might be a drain on memory resources (either because that information must be held until it becomes useful or because using that information sets up expectations for future structures which must be maintained; Gibson, 1998). In addition, another possibility is that readers will not be able to make use of the color as a cue to syntactic category, but might instead be distracted by the color, which would cause them to have comprehension difficulty and result in slower reading.

Finally, the last prediction is that, if there is no change in the observed reading behavior, then this could mean that the syntactic information is ignored even though it is available earlier. It is also possible that the level of prediction done by the processor is normally quite accurate (Staub and Clifton, 2006), so that and providing the part of speech for upcoming words will not boost their predictability over the normal case. In the figure, this possibility is represented by making the size of the bars for the normal reading and experimental conditions equal.

2.0 METHODS

2.1 PARTICIPANTS

Eighty-one undergraduates (twenty-seven in each of three conditions) at the University of Pittsburgh participated in the study for course credit. They were all native English speakers with normal or corrected-to-normal vision.

2.2 EQUIPMENT

Stimuli were presented on PC computers using a program called Linger (Rohde, 2003). Participants were seated approximately 1.5 ft from the monitor and entered commands using a mouse. Approximately 2.3 character spaces equaled 1° of visual angle.

2.3 MATERIALS

Stimuli consisted of 159 sentences varying in length from 6 -27 words (mean = 12.7; stdev = 4.2). Stimuli were presented on a black background. Uncolored words in each sentence were presented in light grey. Colored words were red (#ff1414), blue (#8914ff), teal (#14ffff), and green (#89ff14). These colors were chosen to have identical saturation and luminosity, but hues that are equidistant from each other on the color wheel.

2.4 DESIGN

The experiment consisted of three between-subject conditions and one within-subject condition. The three between-subject conditions were the experimental condition (*consistent color*) and two control conditions (*inconsistent color* and *no color*). In the consistent-color condition certain words (nouns, verbs, prepositions, and determiners) were colored based on their part of speech. These colors were consistent throughout the experiment. The inconsistent-color condition was identical to the consistent-color condition except that the colors for each part of speech changed from sentence to sentence. This condition was designed to be a control for the effect of color independent of the mapping from color to a word's part of speech. In the no-color condition, no words were colored. This condition was designed to simulate normal reading independent of any experimental manipulation. The single within-subject manipulation was that all subjects received a final block of inconsistently colored stimuli. This manipulation was designed to examine dishabituation effects for participants in the consistent-color condition. If subjects make use of color information and, as a result, become faster at reading, then they should slow down during the last block of trials because the color information is no longer reliable.

2.5 PROCEDURE

Before the experiment began, participants read instruction on the computer screen and received the same instructions verbally. They were told that they would be reading sentences and answering yes/no questions about some of them. Participants were all told, regardless of condition, that some of the sentences they read would contain colored words. They were asked to read quickly without sacrificing accuracy.

After reading the instructions, participants had a short practice block consisting of nine sentences to allow them to get used to the procedure. The data from this block was not analyzed. Six of these sentences were presented as they would have been in the inconsistent-color condition and three of them were presented as they would have been in the no-color condition. The remaining 150 sentences were split into five blocks. This division was invisible to subjects and done only for data analysis purposes. These five blocks always contained the same 30 sentences (i.e., sentence 5 is always in block 5), but both the order of sentences within a block and order of blocks within the experiment were randomized. The first four blocks were presented according to the condition the subject was assigned to and the final block was always the inconsistent-color condition.

On each trial, subjects controlled the rate of presentation via mouse clicks. The first mouse-click would make a sentence appear on the screen. The second mouse-click indicated when they had finished reading and caused the sentence to disappear. If six seconds passed between the first mouse-click (to make the sentence appear) and the second mouse-click (to signal that the participant was finished reading), the sentence would disappear and the message "Too Slow!" would appear on the screen. Questions were never asked for items where this occurred. If subjects read the sentence in less than six seconds, there was a 25% chance of a question appearing. No more than five sentences in a row could appear without a question following at least one. Subjects answered questions by using the mouse cursor to press buttons labeled “yes” and “no’ at the bottom of the screen. Response latencies were not analyzed. Subjects received immediate feedback on the accuracy of their response to each question. Response accuracy, latency, and sentence-reading times were recorded for each subject.

3.0 RESULTS

The dependent measures of interest were sentence reading times and accuracies on the questions. Sentence reading times for the consistent-color condition were expected to be significantly faster than for the inconsistent-color and no-color conditions. Accuracy scores were expected to be high for all subjects.

3.1 READING TIMES

Figure 4 shows the relative mean reading times for all three conditions across all five experimental blocks. For the consistent-color condition, the means and standard errors (in parentheses) for the four blocks were 3339ms (65), 3135ms (89), 3134ms (68), and 3059ms (78), respectively. For the inconsistent-color condition the means and standard errors were: 3337ms (108), 3008ms (141), 3065ms (122), and 2974ms (118), respectively. Finally, for the no-color condition, the means and standard errors were: 3464ms (72), 3478ms (76), 3419ms (53), and 3380ms (72), respectively.

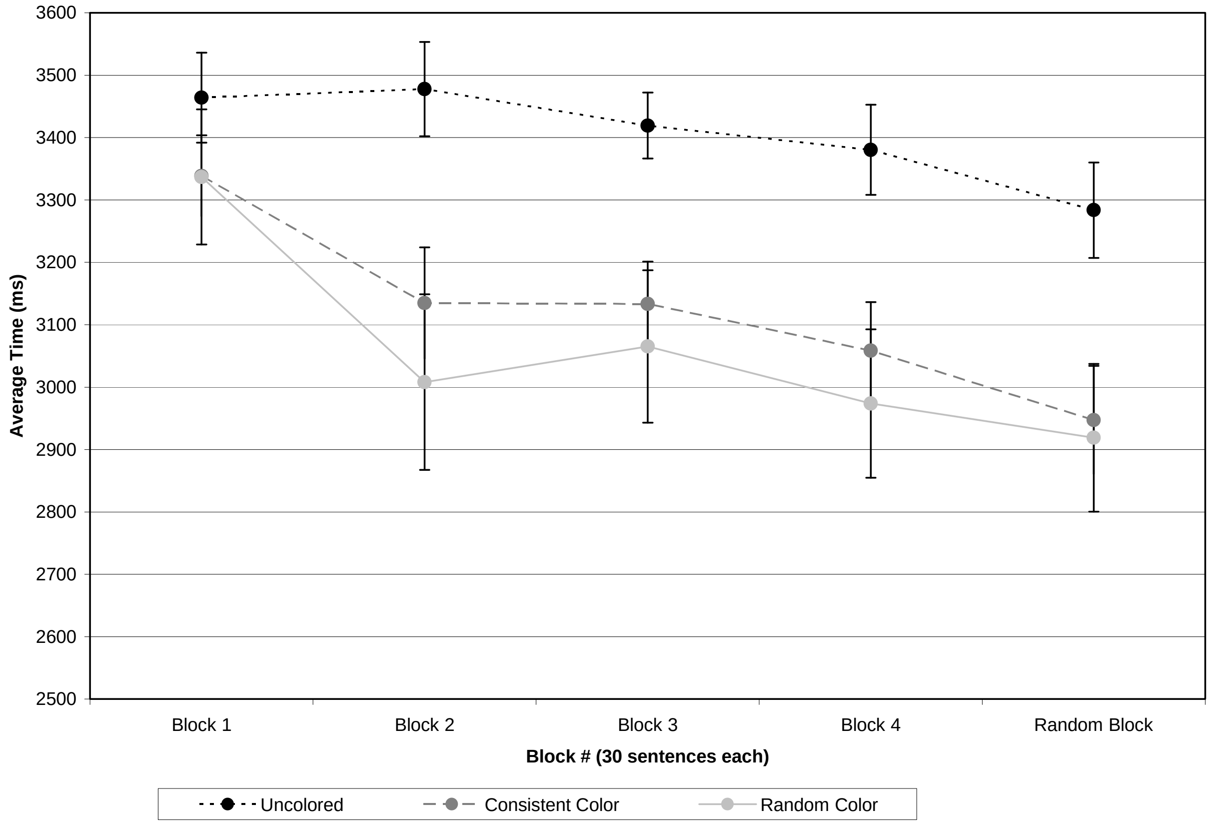

Figure 4

A 4 (block – within subjects) x 3 (condition – between subjects) ANOVA was conducted and there were significant main effects of both block (F(3,234) = 15.7, p < .001) and condition (F(2,78) = 4.6, p = .013), and a significant interaction between the two factors (F(6,234) = 2.8, p = .011).

Pair-wise comparisons were performed to determine what differences drove the main effects. In first block, there were no significant differences among the three conditions (all p's > .15). In the second through fourth blocks, there were significant differences between the no-color and consistent-color conditions (block 2: t = 2.8, p = .01; block 3: t = 3.2, p = .004; block 4: t = 3.3, p = .003) and significant differences between the no-color and inconsistent-color conditions (block 2: t = 3.2, p = .004; block 3: t = 2.7, p = .013; block 4: t = 2.9, p = .007). There were no significant differences between the inconsistent- and consistent-color conditions (all p’s > 0.5).

In the no-color condition, there were no significant differences in reading times across blocks (p’s > 0.15). In the consistent-color condition the first block was read significantly slower than the second through fourth blocks (block 2: t = 3.1, p = .005; block 3: t = 3.5, p = .002; block 4: t = 4.5, p < .001), but there were no significant differences between the remaining blocks (all p’s > 0.1). The same pattern was found for the inconsistent-color condition (block 2: t = 3.6, p = .001; block 3: t = 3.3, p = .003; block 4: t = 5.0, p < .001; all other p’s > 0.25).

The only comparison of interest for the within-subject manipulation in the fifth block (where all subjects received a block of inconsistently colored sentences) was whether the fourth and fifth blocks differed for participants in the consistent-color condition. A pair-wise t-test found a significant difference between the fifth (mean = 2947ms, std. error = 87) and fourth (mean = 3059, std. error = 78) blocks (t = 2.5, p = .018). However, this difference was not in the expected direction.

In summary, the consistent-color condition was read faster than the no-color condition, as expected. The inconsistent-color condition was also read faster than the no-color condition and similar practice effects were found for the two color conditions. The consistent-color condition showed a significant speed-up for the manipulation in the final block, which was also unexpected.

3.2 ACCURACY SCORES

Overall accuracy scores were computed for each subject and then compared. The mean accuracy scores and standard errors (in parentheses) for the three conditions were: uncolored = 0.91 (.008); consistently-colored = 0.916 (.009); and randomly-colored = 0.883 (.015). There was a significant difference among conditions, $F(2,52) = 3.40$, $p = .04$. Pair-wise comparisons revealed this difference to be driven by significant differences between the no-color and inconsistent-color conditions ($p = .046$), and between the consistent- and inconsistent-color conditions ($p = .038$). The inconsistent-color condition resulted in significantly lower accuracy than the other two conditions.

4.0 DISCUSSION

This experiment was designed to learn about the flexibility of the language processor by making syntactic information available earlier than it normally would be available. This question was addressed by a self-paced reading study, where part of speech information was provided to the reader before it would normally become available via a color cue. It was hypothesized that providing part of speech information by way of a consistent color cue would speed reading. This is because the color cue would be available in the periphery, before part of speech information would normally be available. That is, if the parser made use of that early part of speech information, then it should have boosted the predictability of upcoming words and resulted in a speed up in parsing.

The data were consistent with the hypothesis. Both the random- and consistent-color conditions were read more quickly than the uncolored condition. There was a speed accuracy trade-off in the random-color condition. That is, the random-color condition, which was read as quickly as the consistent-color condition, resulted in significantly lower accuracy than both the consistent-color and uncolored-conditions.

It is difficult to say why the random-color condition would lead to a speed-accuracy trade-off. One possible explanation is that the random-colored condition did not serve as a proper control condition. The random-color condition was designed so that the distribution and frequency of the individual colors was as similar as possible to the consistent-color condition.

This meant that words from the same syntactic categories were colored, and that within an individual trial, the colors that were used for each part of speech were consistent (e.g. two nouns would always be the same color). Thus, it is possible that some sort of information about the structure of the sentence was available even in the random-color condition, and that subjects were making use of it. For example, knowing that the syntactic part-of-speech differed for two words immediately following a determiner might allow subjects to anticipate an adjective before a noun. This would mean that the random-color condition could have provided clues to the inherent structure of the sentence even if the colors themselves did not serve as consistent mappings to any particular part-of-speech. Thus, if readers were to make use of this information, then they could have used it in a similar manner to the information about part-of-speech in order to speed their reading. The trade-off for accuracy could have been a result of memory processes; it is possible that in the consistent-color condition, the consistency of the color aided in memory for the subjects and actions of a sentence, and that, in the uncolored-condition, subjects were not distracted by the color.

The within-subject manipulation wherein the fifth block was composed of randomly colored trials did not have the expected effect. Subjects in the consistent-color condition did not experience a significant slow-down. This is not surprising because the random- and consistent-color conditions were not significantly different during the first four blocks. It is also not surprising that there was no effect of the manipulation in the uncolored-condition because it took subjects who started in the colored conditions a full block to show an effect of the color manipulation. This suggests that more trials may have been necessary for subjects to either reject or learn the mapping from color to syntactic part-of-speech.

The comprehension data are difficult to explain because not enough questions were asked to provide information about why the subjects in the random-color condition answered the questions they did incorrectly. The questions were only included to make sure that subjects were trying to read and understand the sentences; questions were not asked after each sentence to prevent interference with learning the mapping between color and part of speech. In the future, additional comprehension questions could be included to learn how the colors are affecting comprehension.

Additionally, because all of the sentences were relatively simple and short, it is not unreasonable to think that the parser would be quite good at making predictions in the absence of the color especially in the case of the determiners, which have the added visual cue of being very short. In the future, it would be more informative to use the color cue to signal upcoming constructions. For example, it could be informative to use a color cue which labeled whether a verb was going to take one or two post-verbal arguments (e.g. the verb “to mail” can be used in the context of “to mail a letter” or in the context “to mail a letter to her mother”). Or a color cue which specified the nature of those arguments, such as one color for a noun phrase and a different one for a prepositional phrase (e.g. the verb “to plunge” can be used in the context of “to plunge the eggs into boiling water” or in the context of ‘to plunge into the swimming pool head-first”). These types of manipulations are less subtle, and might be expected to show more robust learning on the part of subjects.

The main result of this experiment was a speed-accuracy trade-off. The uncolored condition was read slower than the random- and consistent-color conditions; however, subjects’ comprehension question accuracy was lower in the random-color condition than the uncolored and consistent-color conditions. This speed-accuracy trade-off suggests that subjects’ were able to make use of the information provided by the color cues in order to speed-up reading, but in the inconsistent-color condition this information interfered with answering the comprehension questions. The fact that subjects were able to make use of the information provided by the color suggests that syntactic, or structural, information can be used by readers even when that information is provided before it would normally become available. This is consistent with models of reading where information is used as it becomes available and is inconsistent with completely modular theories of reading. If reading were completely modular, then the syntactic part-of-speech information provided by the color would not have been used by subjects to speed-up their reading.

In conclusion, while the interpretation of the results is made difficult by a few factors, they are over-all consistent with the predictions and would support a language comprehension system which is flexible enough to make use of information when it is available.

BIBLIOGRAPHY

Altarriba, J., Kambe, G., Pollatsek, A., & Rayner, K. (2001). Semantic codes are not used in integrating information across eye fixations in reading: Evidence from fluent Spanish-English bilinguals. *Perception & Psychophysics*, 63, 875-890.

Bransford, J.D., and Johnson, M.K. (1972). Contextual prerequisites for understanding: Some investigations of comprehension and recall. *Journal of Verbal Learning and Verbal Behavior, 11*, 717-726.

Chen, E., E. Gibson, and F. Wolf. (2005). Online syntactic storage costs in sentence comprehension. J*ournal of Memory and Language*, 52, 144-169.

Ehrlich, K., and Rayner, K. (1983). Pronoun assignment and semantic integration during reading: Eye movements and immediacy of processing. *Journal of Verbal Learning and Verbal Behavior*, 22, 75-87.

Engbert, R., Longtin, A., & Kliegl, R. (2002). A dynamic model of saccade generation in reading based on spatially distributed lexical processing. Vision Research, 42, 621-636.

Engbert, R., Nuthmann, A., Richter, E. & Kliegl, R. (2005) *Psychoogical Review*, 112, 777–813.

Fiorentini, A. (1989). Differences between fovea and parafovea in visual search processes. *Vision Research*, 29, 1153-1164.

Fodor, J. A. (1983). *Modularity of mind.* Cambridge, MA: MIT press.

Frazier, L. (1987) Theories of sentence processing. In *Modularity in Knowledge Representation and Natural-language Processing* (Garfield, J., ed.), pp. 291–307, MIT Press.

Frazier, L. and Clifton, C. (1989). Successive cyclicity in the grammar and the parser. *Language and Cognitive Processes*, 4.

Frazier, L. and Fodor, J.D. (1978) The sausage machine: a new two-stage model of the parser. *Cognition* 6, 291–325.

Frazier, L. and Rayner, K. (1982). Making and correcting errors during sentence comprehension: Eye movements in the analysis of structurally ambiguous sentences. *Cognitive Psychology*, 14, 178-210.

Friederici, A. (2002). Towards a neural basis of auditory sentence processing.
Trends in Cognitive Science, 6(2), 78–84.

Frisson, S., Rayner, K., & Pickering, M. J. (2005). Effects of contextual predictability and transitional probability on eye movements during reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 31*, 862–877.

Gibson, E. (1998). Linguistic complexity: Locality of syntactic dependencies. *Cognition*, 68, 1-76.

Hagoort, P. (2003).How the brain solves the binding problem for language: A neurocomputational model of syntactic processing. *NeuroImage*, *20*, S18–S29.

Hagoort, P., Hald, Bastiaansen, & Petersson. (2004). Integration of word meaning and world knowledge in language comprehension. *Science,* 304, 438–441.

Hahne, A. and Jescheniak, J.D. (2001).What's left if the Jabberwock gets the semantics? An ERP investigation into semantic and syntactic processes during auditory sentence comprehension. *Cognitive Brain Research*, *11*, 199-212.

Hyona, J., and Bertram, R. (2004). Do frequency characteristics of nonfixated words influence the processing of fixated words during reading? *European Journal of Cognitive Psychology*, *16*, 104–127.

Hyona, J., & Hujanen, H. 1997, Quarterly Journal of Experimental Psychology, 50A(4), 841.

Inhoff, A. W., Briihl, D., & Start, M. (1998). *Parafovea-to-fovea priming during eye fixations in reading.* Manuscript submitted for publication.

Inhoff, A.W., Eiter, B. M., & Radach, R. (2005) Time Course of Linguistic Information Extraction from Consecutive Words During Eye Fixations in Reading. *Journal of Experimental Psychology: Human Perception and Performance*, *31*, 979–995.

Inhoff, A.W., Starr, M., & Shindler, K.L. (2000). Is the processing of words during eye fixations in reading strictly serial? Perception & Psychophysics, 62, 1474-1484.

Kaiser, Elsi and John C. Trueswell (2004) The role of discourse context in the processing of a flexible word-order language. *Cognition* 94(2), 113-147.

Kliegl, R., Grabner, E., Rolfs, M., & Engbert, R. (2004). Length, frequency, and predictability effects of words on eye movements in reading. *European Journal of Cognitive Psychology, 16*, 262-284.

MacDonald, M.C., Pearlmutter, & Seidenberg. (1994). Lexical nature of syntactic ambiguity resolution. *Psychological Review*, 101, 676–703.

Marslen-Wilson, W.D. and Tyler, L.K. (1980) The temporal structure of spoken language understanding. *Cognition* 8, 1–71.

McConkie, G. W. & Zola, D. (1979). Is visual information integrated across successive fixations in reading? *Perception & Psychophysics*, 25, 211-224.

TF Munte, M Matzke, & S Johannes (1997). Brain activity associated with syntactic incongruencies in words and pseudo-words. *Journal of Cognitive Neuroscience*, 9, 318-329.

Murray, W., & Rowan, M. (1998). Early, mandatory, pragmatic processing. *Journal of Psycholinguistic Research, 27*, 1-22.

Murray, W. S. (1998). Parafoveal pragmatics: In G. Underwood (Ed.), Eye guidance in reading and scene perception (pp. 181-200). Oxford, England: Elsevier.

Pollatsek, A., Lesch, M., Morris, R. K., & Rayner, K. (1992). Phonological codes are used in integrating information across saccades in word identification and reading. *Journal of Experimental Psychology: Human Perception and Performance*, 18, 148-162.

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin*, 124, 372-422.

Rayner, K., Ashby, J., Pollatsek, A., & Reichle, E. D. (2004). The effects of frequency and predictability on eye fixations in reading: Implications for the E-Z Reader model. *Journal of Experimental Psychology: Human Perception and Performance, 30*, 720-732.

Rayner, K., Balota, D.A., & Pollatsek, A. (1986). Against parafoveal semantic preprocessing during eye fixations in reading. *Canadian Journal of Psychology*, 40, 473-483.

Rayner, K., McConkie, G. W., & Zola, D. (1980). Integrating information across eye movements. *Cognitive Psychology, 12,* 206-226.

Rayner, K., and Morris, R. K. (1992). Eye movement control in reading: Evidence against semantic preprocessing. *Journal of Experimental Psychology: Human Perception and Performance, 18,* 163-172.

Rayner, K., Warren, T., Juhasz, B., & Liversedge, S. P. (2004). The effect of plausibility on eye movements in reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 30,* 1290–1301.

Rayner, K., Well, A. D., & Pollatsek, A. (1980). Asymmetry of the effective visual field in reading. *Perception & Psychophysics*, 27, 537-544.

Rayner, K., Well, A.D., Pollatsek, A., & Bertera, J.H. (1982). The availability of useful information to the right of fixation in reading. *Perception & Psychophysics, 31*, 537-550.

Reichle, E. D. & Laurent, P. (2006). Using reinforcement learning to understand the emergence of “intelligent” eye-movement behavior during reading. *Psychological Review*, 113, 390-408.

Reichle, E. D., Pollatsek, A., & Rayner, K. (2006). Modeling the effects of lexical ambiguity on eye movements during reading. In R. P. G. Van Gompel, M. F. Fischer, W. S. Murray, & R. L. Hill (Eds.), Eye movements: A window on mind and brain. Oxford University Press. Manuscript in press.

Reichle, E. D., Pollatsek, A., Fisher, D. L., & Rayner, K. (1998). Toward a model of eye movement control in reading. *Psychological Review,* 105, 125-157.

Reichle, E. D., Rayner, K., & Pollatsek, A. (1999). Eye movement control in reading: Accounting for initial fixation locations and refixations within the E-Z Reader model. Vision Research, 39, 4403-4411.

Reichle, E. D., Rayner, K., & Pollatsek, A. (2004). The E–Z Reader model of eye movement control in reading: Comparisons to other models. *Behavioral and Brain Sciences,* 26, 445-476.

Reilly, R. (1993). A connectionist framework for modeling eye-movement control in reading. In G. d’Ydewalle & Van Rensbergen (Eds.), Perception and cognition: Advances in eye movement research (pp. 191-212). Amsterdam: North Holland.

Reilly, R. & Radach, R. (2002). Foundations of an interactive activation model of eye movement control in reading. In J. Hyönä, R. Radach, & H. Deubel (Eds.), The mind's eye: Cognitive and applied aspects of eye movements. Oxford: Elsevier Science, in press.

Staub, A. and Clifton, C., Jr (2006) Syntactic prediction in language comprehension: evidence from either. . .or. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 32, 425–436.

Staub, A. and Clifton C., Jr. (2006, March) Effects of a word's status as a predictable phrasal head on lexical decision and eye movements. 19th CUNY Conference on Human Sentence Processing, New York, NY.

Sturt, P. (2003). The time-course of the application of binding constraints in reference resolution. *Journal of Memory and Language*, *48*(3), 542–562.

Tanenhaus, M. K., Spivey-Knowlton, M. J., Eberhard, K. M., & Sedivy, J. C. (1995). Integration of visual and linguistic information in spoken language comprehension. *Science*, 268, 1632-1634.

Treisman, A., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology*, 12, 97-136.

Vitu, F., Brysbaert, M. & Lancelin, D. (2004) A test of parafoveal-on-foveal effects with pairs of orthographically related words. *European Journal of Cognitive Psychology*, 16, 154-177.

Warren, T. & McConnell, K. (2006). Effects of building and maintaining syntactic predictions on eye-movements in reading. Poster presented at the 19th annual CUNY conference on human sentence processing. New York, NY.

Warren, T. & McConnell, K. (in press). Investigating effects of selectional restriction violations and plausibility violation severity on eye-movements in reading. *Psychonomic Bulletin & Review.*

Warren, T., McConnell, K. & Rayner, K. (2007). The time course of different kinds of knowledge use during reading comprehension. Poster presented at the 20th annual CUNY conference on human sentence processing. San Diego, CA.