The Effect of Working Memory and Syntactic Complexity on Sentence Comprehension

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ABSTRACT

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The present study explored comprehension of spoken sentences as a result of manipulations of sentence length and complexity. Young adult participants heard a series of sentences that varied in type (subject-relative and object-relative) and sentence complexity (6-word and 10-word). These sentences were further manipulated in complexity through the addition of prepositional phrases into varying points within the 10-word sentences (short noun-verb gap and long noun-verb gap). Response accuracy was subject to an ANOVA, which revealed significant main effects of sentence type and sentence complexity, with the effects moderated by a significant Sentence Type X Sentence Complexity interaction. Results support decreased comprehension accuracy for more complex sentences. Response latencies were subject to an ANOVA, resulting in significant main effects of sentence type and sentence complexity, with effects moderated by a significant Sentence Type X Sentence Complexity interaction. Results suggest that for 6-word and 10-word long noun-verb gap sentences, increases in sentence complexity leads to increased response time, however 10-word short noun-verb gap sentences did not.
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The Effect of Working Memory and Syntactic Complexity on Sentence Comprehension

Conversation is an inevitable and essential part of human social interaction. As individuals converse in daily life they not only need to hear auditory input, but also translate the heard acoustic patterns into meaningful phonemes and words which can be analyzed and processed for structure and meaning. Ordinary conversation, which occurs at an average speech rate of 140 to 180 words per minute, requires prompt processing that must occur as new information is rapidly presented to the listener. At the sentence level listeners must determine the syntactic structure that they are hearing and relate the individual word meanings to one another in order to express content (Caplan et al, 1998, Chomsky, 1996). Thus, while seemingly effortless, success in this task requires that listeners not only allocate resources for comprehension of individual words, but also to maintain representations of word meanings and relational structures in order to understand the sentence as a whole. This requires the utilization of working memory as well as application of syntactic rules, and it is the successful concurrent use of these two processes that allows humans to communicate as they do.

Working memory resources are vital in holding information that has been heard in an active state for comprehension in context. It has been seen that sentences that are more syntactically complex are processed with decreased accuracy, as language comprehension utilizes multiple processes in parallel drawing from a single limited pool of resources (Fallon et al, 2006, Just & Carpenter, 1992). Less is known, however, about what specific manipulations of syntactic complexity cause the greatest alteration in performance on sentence comprehension tasks. It is the goal of this research to observe the effect of
increasing memory load and specific manipulations of syntax on young adult participants, in order to further understand this phenomenon.

**Perceptual and Cognitive Challenges in Sentence Comprehension**

Comprehension of spoken language often occurs without apparent effort, despite its evident complexity. In order to comprehend spoken language, one of the first and most important features of understanding is perceptual recognition. One must first hear the acoustic patterns at a level that allows for comprehension. These acoustic patterns make up phonemes, or basic units of speech that compose meaningful units. Combined phonemes make up the lexicon, or the pool of words within a language that are used to express concepts, including objects, actions, and modifiers (Wingfield & Tun, 2007). Listeners must determine what words of the lexicon the phonemes are forming, so that nouns, verbs, and other elements of a sentence can be identified in order to understand the overarching theme or meaning of the sentence (Wingfield & Tun, 2007).

Adding to the complexity of sentence comprehension, the quality of speech signals are often not as good as it may seem. Many words are under-articulated in everyday speech, to the extent that were they removed from their context they would be incomprehensible (Wingfield & Tun, 2007). That is, understanding and recognizing spoken language at a perceptual level may require an increased exertion of cognitive effort. Thus before even exploring the effects of working memory load and syntactic complexity, it is important to understand that spoken language, while seemingly natural, is an effortful process. Despite this, young adults with good hearing are quite adept at rapidly perceiving and comprehending speech.

**The Role of Working Memory in Sentence Comprehension**
Successful perceptual recognition of sounds and lexical elements of speech is merely one of the many effortful processes of sentence comprehension. Working memory is used in conjunction with perceptual recognition, as a necessary means of organizing the identified lexical elements. The working memory system, which is thought to temporarily hold heard speech in the consciousness for integration with new information, allows one to briefly store and coordinate information for processing. Thus working memory serves to keep heard words in one’s consciousness in order to be integrated with previous speech (Wingfield & Tun, 2001). This is essential for comprehending meanings of individual words and subsequently the message of the sentence those words make up.

Were an individual to lack any capacity for working memory, comprehending a sentence of any substantial length would be impossible. By the end of the sentence, the first words would no longer be present for manipulation in consciousness, and as such not able to be related to and associated with the other words. Although complete lack of working memory is incredibly rare, (Butterworth, Campbell, & Howard, 1986, Martin, 1990), working memory load can be manipulated to simulate difficulty through increasing sentence length, and consequently working memory demand. Insertion of additional words to a sentence requires a listener to hold more information in the consciousness, and this strain increases the likelihood of errors.

**The Role of Syntactic Complexity**

While the principle of increased working memory load due to additional words is also seen in recall of words in a list, in the context of a sentence there exists a unique reason for increased working memory use. As has been previously stated, a sentence is a unit of words being heard together and in relationship with one another. These
relationships are determined according to a system of rules that dictates the meaning of
the sentence as a single unit. The rules, known as syntax, determine how combining
lexical elements occurs, or how the elements of a sentence in speech relate to one another
(Fallon et al., 2006). As was previously suggested, recalling words previously heard is
necessary for processing, but processing goes beyond merely recalling, which is where
syntax enters. Working memory provides the means of holding words in consciousness
specifically so that a listener can manipulate the words in order to apply the rules of
syntax to them. It has been seen that altering a sentence’s syntax, including through the
addition of new words, increases the burden on working memory, which can lead to
flawed or slowed sentence comprehension (Wingfield & Tun, 2001, Carpenter et al.,
1994).

Understanding of syntactic structure and the semantic relationships between
words allows listeners to analyze heard information and comprehend the complex
thoughts and intentions being conveyed by the sentence. However, even with a basic
understanding of typical syntax, a listener must remain attentive, engaging working
memory in order to utilize the knowledge of syntax for proper comprehension. While the
rules of syntax provide a mapping of how words relate to one another, not all sentences
follow simple syntax. Most sentences in ordinary conversation follow certain typical
rules that can be easily and rapidly predicted by the listener. These sentences are often
considered to be canonical, as they are commonly found in language. Increased
experience or familiarity with syntactic structures, including canonical syntax, has been
seen to lead to more efficient processing (Caplan et al., 2011, Reali & Christiansen, 2007,
Wells, Christiansen, Race, Acheson & MacDonald, 2009). Research suggest that non-
canonical, or atypical, sentences and are known to be more complex and more difficult to process, often causing errors in comprehension accuracy and speed (Cooke et al., 2001, Ferreira et al., 1996). In hearing such atypical sentences, listeners must engage more with the syntax in order to have a correct understanding of the relationships between elements.

A contrast between two types of sentence structure have received considerable study in previous research (Just, Carpenter, Keller, Eddy, & Thulborn, 1996, Fallon et al., 2006, Stine-Morrow, Ryan, & Leonard, 2000); sentences with subject relative embedded clauses and sentences with object relative embedded clauses. These sentences differ in structural complexity but are superficially similar, as they are comprised of the same basic elements, and thus have been used in many instances to study the effects of syntactic complexity. The first two types sentences have received considerable study in previous research. A subject-relative sentence has a syntactic structure comprised of a primary noun phrase that is the agent of an action, a verb and a secondary noun phrase that serves as the recipient of the action. An example of a subject-relative sentence is ‘boys that hug girls are nice’. In this sentence ‘boys’ serves as the primary noun phrase (or agent of the action ‘hug’), while ‘girls’ serves as the secondary noun phrase, or recipient of the indicated action. Conversely, in an object relative sentence, the agent of the action is the secondary noun phrase, while the primary noun phrase acts as the recipient of the action. An example of an object relative sentence, ‘boys that girls hug are nice,’ displays this form, as the noun phrase ‘boys’ is no longer the agent but the recipient of the action (Cooke et al., 2001, Fallon et al., 2006, Just et al., 1996, Stine-Morrow et al., 2000).
The subtle differences in syntax found in subject and object relative sentences can significantly impact one’s capacity for rapid and accurate comprehension. Sentences presented in the subject-relative form are more rapidly and more accurately comprehended than those in the object-relative form, due to the alteration in cognitive demand as one processes the differing syntax (Wingfield et al., 2003, Cooke et. al, 2001, Just & Carpenter, 1992, Waters et al., 2003). As non-canonical sentences, the structure of an object-relative sentences is considered to be more complex due to the fact that it is not commonly found in typical conversation, and thus is more difficult to process (Ferreira et al., 1996).

**Sentence Length Versus Syntactic Complexity**

As has been previously suggested, a combination of sentence length and complexity plays directly into the amount of working memory necessary for correct comprehension. As subject and object relative sentences are differentially syntactically complex, they are commonly used in research exploring the effects of syntactic complexity. The effect of increased sentence length and complexity of these sentence types is a topic less well explored. In this study we chose to investigate a specific manipulation of these sentences through maintaining and lengthening the noun-verb gap. This gap is the space that exists between the noun phrase that relates to the actor of a sentence (in subject-relative sentences, the primary noun phrase, in object-relative sentences, the secondary noun phrase) and verb that indicates the action. For example, in the subject relative sentence ‘boys that hug girls are nice’, the noun-verb gap exists between ‘boys’ and ‘hug’. Adding additional words into this space between two of the
centrally important portions of the sentence results in more complex and non-canonical syntax.

A prepositional clause, made up of a prepositional phrase, modifiers, and a noun, can be added to this noun-verb gap, lengthening the space without altering the roles of the centrally important features of the sentence (the noun phrase and verb). In a study using written sentences, presented in a word-by-word fashion, Cooke et al. (2001) found that when lengthened, there was an increase in the amount of time necessary for one to attribute meaning to the sentence. Specifically, as sentence length increased in object-relative sentences, the amount of time it took participants to identify the agent of the action increased (Cooke et al., 2001).

Cooke et al. also showed that placement of these words plays an important role in the rate of sentence comprehension in visually presented stimuli. The addition of words in a placement that maintains a short noun-verb gap, while more taxing on working memory, does not influence the key terms (the noun phrase and verb), and thus is considered to be in a non-critical placement (e.g. Boys that hug girls with bright blue eyes are nice). As can be seen, the additional phrase does not further separate the key terms for determining the agent of the action (‘boys’ and ‘hug’). Conversely, when the noun-verb gap is lengthened by the addition of a prepositional clause it is considered to be at a critical point, (e.g. Boys with bright blue eyes that hug girls are nice). In this situation ‘boys’ is farther from ‘hug’, and there is an increased temporal gap between hearing the two terms, which is thought to increase the amount of time it takes to identify the agent of the action. As is evident, the additional words create a strain on cognitive load by increasing needed working memory due to the more complex syntax that stems from
separation of the noun phrase and the verb (Cooke et. al, 2001). To what degree alterations of syntactic complexity and memory load impacts ones ability to successfully and rapidly comprehend similar sentences in auditory stimuli is still unknown.

The Goal of This Thesis

It is the goal of this thesis to expand upon previous studies that have demonstrated the impact of subject-relative and object-relative sentences, specifically those with short and long noun-verb gaps on comprehension of auditory stimuli. In this study we will explore the addition of four-word prepositional subordinate clauses to subject relative and object relative sentences in positions that result in both short and long noun-verb gaps in order to see if there is an effect on accuracy of a comprehension response. The sentences will be the 6 types illustrated in Table 1: 6-word subject relative, 10-word subject relative with short noun-verb gaps, 10-word subject relative with long noun-verb gaps, 6-word object relative, 10-word object relative with short noun-verb gaps, and 10-word object relative with long noun-verb gaps. These sentences with additional words show an increase in working memory demand without altering the basic syntactic form, and thus allow an exploration of the effect of the subject, object relative syntactic manipulation, sentence length, and the additional words respectively.

Table 1. Example of Sentence types

<table>
<thead>
<tr>
<th>Sentence Type</th>
<th>Stimulus Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject Relative</td>
<td>Boys that hug* girls are nice</td>
</tr>
<tr>
<td>(6-word)</td>
<td></td>
</tr>
<tr>
<td>Subject Relative</td>
<td>Boys that hug* girls with light blue eyes are nice</td>
</tr>
<tr>
<td>(10 word, short noun-verb gap)</td>
<td></td>
</tr>
<tr>
<td>Subject Relative</td>
<td>Boys with light blue eyes that hug* girls are nice</td>
</tr>
<tr>
<td>(10 word, long noun-verb gap)</td>
<td></td>
</tr>
<tr>
<td>Object Relative</td>
<td>Boys that girls* hug are nice</td>
</tr>
<tr>
<td>(6-word)</td>
<td></td>
</tr>
<tr>
<td>Object Relative</td>
<td>Boys with light blue eyes that girls* hug are nice</td>
</tr>
</tbody>
</table>
As the literature suggests, it is hypothesized that sentence length will show a significant effect on sentence comprehension accuracy and response time, with ten-word sentences resulting in significantly lower accuracy than their six-word sentence counterparts. It is also hypothesized that syntactic complexity of sentences will impact sentence comprehension, decreasing comprehension accuracy due to an increase in working memory load. Specifically, it is hypothesized that object-relative sentences will show significantly less accuracy than subject-relative sentences among all participants. Finally, we posit that lengthening six-word sentences to ten-word sentences with clause additions in a position that increases the noun-verb will decrease sentence comprehension and increase latency significantly more than additions that result in an unaltered noun verb gap. Our primary comprehension measure will be accuracy at determining the gender of the agent of the action described in the sentence. As a secondary measure we will also record participants latencies to correct responses as measured from several possible points after and within the sentence.
Methods

Participants

Twenty-four participants (7 male, 17 female) participated in the study. Participants were volunteer university students with ages ranging from 18 to 22 ($M=20.42$, $SD=1.4$). All participants were native English speakers of American English, with normal or corrected to normal vision, that reported themselves to be in good health. All participants were tested for pure-tone hearing acuity across the frequencies ranging from 250 Hz. to 8,000 Hz., using standard audiometric procedures (Harrell, 2000). Pure-tone average (PTA) as defined across 500, 100, and 2000 Hz) was calculated. PTAs for the participants ranged from 1.7 to 15.0 Hz in the left ear ($M=6.9$, $SD=3.5$) and from 0.0 to 16.7 ($M=7.9$, $SD=4.2$), which falls into the range that is typical considered to be clinically normal for speech (less than 25 dB HL) (Katz, 2002).

Stimuli

Subjects heard stimuli in the form of spoken sentences presented through headphones. These sentences were based on 72 six-word sentences, each consisting of two nouns, representing the agent and recipient of the action respectively, and a verb representing the action. These sentences were presented in the subject relative (“Boys that hug girls are nice”) and object relative (“Boys that girls hug are nice”) form. These sentences were counterbalanced to include sentences with either a female or male agent in each context; totaling 288 six-word subject relative and object relative base sentences.
For each of the four types of aforementioned sentences (subject relative-male, object relative-male, subject relative-female, object relative-female) a memory load manipulation took place in the form of an addition of a four-word clause. The additional clauses, which consisted of a prepositional phrase (typically following the form preposition, two modifiers, and a noun), were placed in a critical or non-critical position in the sentence. In the critical position, the four-word phrase was inserted between the noun phrase (the agent of the action) and the verb, thus creating a long antecedent gap. An example of a subject relative sentence with this addition in the critical point is “Boys with long brown hair that hug girls are nice,” while an example of an object relative sentence with the same linguistic adjustment is “Girls that boys with long brown hair hug are nice”. Conversely the linguistically non-critical position placed the additional phrase outside of the action-agent pair resulting in a short antecedent gap (e.g., “Boys that hug girls with long brown hair are nice” in the subject relative and “Girls with long brown hair that boys hug are nice” in the object relative).

Procedure

Each participant was tested individually in a sound-attenuated room. Participants were informed of the purposes of the study and given a chance to ask questions. Once participants had given their informed consent, they were given a pure tone audiometric screening to assess hearing acuity prior to commencing the study. The experimenters informed participants that they would hear a series of sentences varying in complexity (syntax) and length. Participants were advised to listen closely to each sentence, and were instructed to indicate the gender of the agent of the action as rapidly as possible without
making errors. Participants were encouraged to respond prior to the end of hearing the sentence, if they were able to determine the agent.

Participants responded by pressing a computer key labeled ‘male’ or ‘female’. The key press response was counterbalanced across participants, such that half of the participants responded with male as the left key press and female as the right, while the other half responded in the opposite manner. Accuracy and response latency were recorded with E-Prime 2.0 presentation software (Psychology Software Tools, Pittsburgh, PA).

Subjects were first given a brief 10-sentence practice session, and second opportunity to ask questions before commencing with the study. Subjects were then presented with each of the sentences through headphones at a self-determined audible level.

Each participant heard 96 sentences derived from the aforementioned base sentences. Researchers used a within-subject design, in which each participant heard 12 subject relative 6-word sentences, 12 object relative 6-word sentences, 12 subject relative 10-word sentences (non-critical position), 12 subject relative 10-word sentences (critical position), 12 object relative 10-word sentences (non-critical position), and 12 object relative 10-word sentences (critical position). No participant heard the same base sentence, or a sentence derived from the same base sentence, more than once. Counterbalancing across participants occurred such that upon completion of the experiment every base sentence and its 6 permutations were heard an equal number of times. Stimuli were presented using a mixed-list design with order varied between participants. Additionally, 12 active conjoined 6-word sentences (e.g. Boys hug girls and
are nice) and 12 active conjoined 10-word sentences (e.g. Boys hug girls with long brown hair and are nice) were heard as filler sentences. These were presented intermixed with test sentences throughout the study. Stimuli were presented over binaural earphones at a comfortable listening level.

**Cognitive Measure**

Each participant was assessed in: (a) Trail-Making Test Part A and B for testing executive function (Lezak, 1995); (b) the Visual Stoop test of color reading interference to measure cognitive flexibility (Mueller, 2009), (c) the Daneman and Carpenter Reading span for working memory (McCabe, 2012, Daneman & Carpenter, 1980), and (d) a measure of speed using the Digit-Symbol substitution task (Wechsler Adult Intelligence Scale Third Edition; Wechsler, 1997). Finally, a Shipley Institute Living Scale Vocabulary test was administered (Zachary, 1986). These cognitive tests were all presented visually in order to remove a potential confound of hearing acuity. The results of the cognitive battery are presented in table 2.

**Table 2. Results of Cognitive Battery**

<table>
<thead>
<tr>
<th>Sentence Type</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trail-Making Part A</td>
<td>22.66</td>
<td>6.79</td>
</tr>
<tr>
<td>Trail-Making Part B</td>
<td>52.98</td>
<td>12.48</td>
</tr>
<tr>
<td>Visual Stoop: Consistent</td>
<td>672.90</td>
<td>95.40</td>
</tr>
<tr>
<td>Visual Stoop: Conflict</td>
<td>809.10</td>
<td>141.47</td>
</tr>
<tr>
<td>Visual Stoop: Errors</td>
<td>.064</td>
<td>.20</td>
</tr>
<tr>
<td>Daneman and Carpenter Reading Span</td>
<td>10.75</td>
<td>2.99</td>
</tr>
<tr>
<td>Digit-Symbol: Baseline</td>
<td>149</td>
<td>14.13</td>
</tr>
<tr>
<td>Digit-Symbol</td>
<td>73.38</td>
<td>11.67</td>
</tr>
<tr>
<td>Shipley Institute Living Scale Vocabulary Test</td>
<td>14.04</td>
<td>1.46</td>
</tr>
</tbody>
</table>
Results

Comprehension Accuracy

The main comprehension accuracy findings are shown in Figure 1, which plots the percent of correct responses (comprehension accuracy) for subject relative (SR) and object relative (OR) 6-word, 10-word short noun-verb gap, and 10-word long noun-verb gap sentences.

Response accuracy was high for all participants ranging from 78% to 99% across all conditions with performance at near ceiling in several conditions. We submitted the response data to a 2 x 3 analysis of variance (ANOVA) with sentence type (subject-
relative, object-relative) and sentence complexity (6-word, 10-word non critical position, 10-word critical position) as within-participant variables. As figure 1 suggests, there was a significant main effect of syntax $F(1,23)=15.30, p<.001, \eta^2_p = .39$, as well as a significant main effect of length $F(2,46)=6.43, p=.003, \eta^2_p = .22$. A significant interaction effect was found between syntax and length $F(2,46)=6.73, p=.003, \eta^2_p = .23$.

A paired-samples t-test indicated that response accuracy was significantly higher for subject relative 6 word sentences ($M=.99, SD=.02$) than 6-word object relative sentences ($M=.90, SD=.12$), $t(23)=3.70, p=.001$. Subject relative 10-word short noun-verb gap sentences ($M=.97, SD=.05$) did not show significantly higher response accuracy than 10-word short noun-verb gap object relative sentences ($M=.92, SD=.17$), $t(23)=1.50, p=.14$. Finally 10-word long noun-verb gap subject relative sentences ($M=.99, SD=.03$) showed significantly higher accuracy than 10 word long noun-verb gap object relative sentences ($M=.78, SD=.24$), $t(23)=3.99, p=.001$.

As can be seen in figure 1, there were no significant differences between the various sentence complexities of sentences for subject relative sentences, as suggested by figure 1. Responses were not significantly different for subject relative short noun-verb gap ($M=.97, SD=.05$) than for subject relative long noun-verb gap ($M=.99, SD=.03$) sentences $t(23)=-.83, p=.42$. Similarly, no differences were seen between subject relative 6 word ($M=.99, SD=.02$) sentences and subject relative 10 word short noun-verb gap ($M=.97, SD=.05$), $t(23)=-2.00, p=.06$ as well as subject relative 6 word sentences ($M=.99, SD=.02$) and subject relative long noun-verb gap ($M=.99, SD=.03$) sentences $t(23)=-.81, p=.43$. 
Significant differences were seen among object relative sentences. Paired comparisons revealed that responses were significantly different for 10-word short noun-verb gap ($M=.92$, $SD=.17$) and 10 word long noun-verb gap ($M=.78$, $SD=.24$) object relative sentences, $t(23)=3.01$, $p=.006$. There were also significant differences between the 10-word long noun verb gap sentences ($M=.78$, $SD=.24$) and the 6 word object relative sentences ($M=.90$, $SD=.12$), $t(23)=2.52$, $p=.02$, however no significant differences were found between the short object relative sentences, and the long object relative sentences with a short antecedent gap $t(23)=.926$, $p=.364$.

Response Latencies

Figure 2 shows the mean amount of time (ms) that it took for subjects to respond with accurate gender judgments measured from the beginning of the sentence, for subject relative (SR) and object relative (OR) 6-word, 10-word short noun-verb gap, and 10-word long noun-verb gap sentences. For all analyses latencies are only reported for correct responses.
Response times for latencies greater than two standard deviations above and below the resulting means for each sentence type were removed from analysis. These accounted for less than 4.5% of the data. Latencies were calculated from the earliest point of time at which a listener would be able to determine the agent of the action. These points are shown in the sample sentences given in Table 2. For this analysis response times for incorrect responses were discarded. Figure 2 shows the response times from the earliest point of possible understanding for SR and OR 6-word, 10-word short noun-verb gap, and 10-word long noun-verb gap.

A 2 x 3 ANOVA was conducted on the latencies to corrected responses from these earliest points. The analysis resulted in a significant main effect of syntax (object relative, subject relative), $F(1,23)=52.52$, $p<.001$, $\eta_p^2=.70$, and a main effect for sentence
complexity (6-word, 10 word short noun-verb gap, 10 word long noun-verb gap)

$F(2,46)=39.61, p<.001, \eta^2_p=.63$. Finally, a significant Syntax X Complexity interaction was found $F(2,46)=161.74, p<.001, \eta^2_p=.88$.

Paired comparisons suggested that significant differences existed between syntax for all sentence complexities. It was found that response times were significantly higher for 6-word object relative sentences ($M=2086.43, SD=583.57$) than 6 word subject relative sentences ($M=1653.59, SD=445.43$), $t(23)=5.25, p<.001$. Similarly, response times were significantly higher for object relative 10 word long noun-verb gap sentences ($M=3433.07, SD=946.89$) than subject relative 10 word long noun-verb gap sentences ($M=1463.01, SD=506.19$), $t(210)=12.67, p<.001$. Surprisingly, response times were significantly lower for object relative 10-word short noun-verb gap ($M=1514.56, SD=388.32$) than subject relative 10-word short noun-verb gap sentences ($M=25492.12, SD=621.63$), $t(23)=-10.43, p<.001$.

In exploring the main effect of sentence complexity a planned comparisons of the response times of 6-word object relative sentences ($M=2086.43, SD=583.57$) and 10-word short noun-verb gap object relative sentences ($M=1514.56, SD=388.32$) resulted in the latter having significantly faster response times, $t(23)=-6.83, p<.001$. Response times for object relative 10 word long noun-verb gap sentences ($M=3433.07, SD=946.89$) were found to be significantly longer than object relative 6-word sentences ($M=2086.43, SD=583.57, t(23)=9.97, p<.001$. Finally, it was found that object relative 10 word short noun-verb gap sentences ($M=1514.56, SD=388.32$) were responded to significantly quicker than 10 word object relative long noun-verb gap sentences ($M=3433.07, SD=946.89$), $t(23)=-12.49, p<.001$. 

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The final series of planned comparisons was analyzed in order to explore the differences based upon sentence complexity in subject relative sentences. It was found that subject relative 6-word \((M=1653.59, SD=621.63)\) had significantly shorter response times than the subject relative 10 word short noun-verb gap sentences \((M=2492.12, SD=621.63)\), \(t(23)=10.09, p<.001\). Significant differences were found between the subject relative 6-word sentences \((M=1653.59, SD=621.63)\) and the subject relative 10-word long noun-verb gap sentences \((M=1653.59, SD=445.43)\), \(t(277)=-2.82, p=.01\). Lastly, the comparison of subject relative 10-word short noun-verb gap sentences \((M=2492.12, SD=621.63)\) and long noun-verb gap sentences \((M=1463.00, SD=406.19)\) resulted in subject relative 10 word short noun-verb gaps sentence having significantly longer response times, \(t(23)=11.69, p<.001\).
Discussion

It was the purpose of this Thesis to explore how auditory communication of sentences was effected by variations in working memory demands inherent in different types of sentence constructions. Although it has been shown for word-by-word reading times that lengthening a sentence and altering syntactic complexity slows sentence comprehension and decreases comprehension accuracy (Cooke et al., 2001), one may not be able to generalize this finding to natural speech produced in a normally fluent manner. Our results suggest that such manipulations when presented in the form of auditory stimuli do cause a systematic decrease in comprehension accuracy.

Comprehension Accuracy Results

The current accuracy results indicate that the syntactic complexity of a sentence has a notable effect on one’s ability to comprehend the sentence, supporting previous findings (Wingfield, Peele, & Grossman, 2003, Cooke et al., 2001). Specifically, our results suggest that sentences with a subject relative form are significantly easier to comprehend (resulting in higher percent accuracy for the comprehension) than object relative sentences. What is most interesting about this finding is that our accuracy data suggests that this holds true for both 6-word and 10-word long noun-verb gap sentences. Significant differences were found when comparing subject relative and object relative forms of these sentences. This suggests that individuals are better equipped to respond to judgments when they are expressed in less complex sentences than those that are more
complex. We posit that this finding suggests that the additional working memory load that is utilized to hold the terms of more complex sentences in one’s consciousness impacts how one is able to make judgments about the internal elements of the sentence. The smaller working memory demand of subject relative sentences may be due to the fact that these sentences are more canonical in syntax, and thus participants were more familiar with the syntax. Thus our findings support previous research by Reali and Christiansen (2007), in suggesting that familiarity with relative clauses leads to improved accuracy.

Interestingly, however, this effect was not present in the 10 word short noun-verb gap sentences, which did not show a significant difference in accuracy. We believe that the reason that these sentences did not show significant differences is due to the fact that responses to both object and subject relative versions of these sentences were near ceiling. While accuracy was lower for the object relative than the subject relative, in general individuals were able to respond accurately to these sentences. Response times suggest that for this particular type of sentence participants spent a longer time determining the agent of the action, possibly suggesting that the higher accuracy was a result of this additional time spent listening.

Syntactic complexity was manipulated in terms of sentence type (subject and object relative clause sentences) as well as a second factor: placement of an added in prepositional phrase. Based on the work of Cooke et al. (2001) it was hypothesized that adding a prepositional phrase to the sentence in between the head noun phrase (the agent of the action) and the subsequent verb would create more complex sentences than when the phrase was added at a different, less critical point in the sentence. In examining
response accuracies, it is notable that subject relative sentences did not show this expected effect. This may have been due to the fact that response accuracy for these sentences was near ceiling level, and that despite the manipulation subject relative sentences remain simple enough that they can be easily comprehended. Interestingly, however, our accuracy data suggests that more complex sentences (object relative), are susceptible to this effect. We found significant difference in accuracy when comparing the simpler object relative sentences (6-word and 10-word short noun-verb gap) to the complex 10-word sentences with a long noun-verb gap created by the additional prepositional phrase. This finding suggests that the location of the prepositional phrase does have an effect on comprehensibility of sentences, but only those that are non canonical. Again this supports the suggestion that less familiar sentences are more difficult to accurately comprehend.

Interestingly the pure effect of sentence length on sentence comprehension accuracy was not significantly different for subject relative sentences, nor for object relative sentences when comparing the 6 word sentences and 10 word sentences with a short noun-verb gap insertion. This is notable as it does not support the suggestion that additional word load from the new propositional phrase increased the amount of information that was held in working memory, thus making integration with previous speech more difficult, as was hypothesized. The exception to this finding was the comparison of object relative 6 word sentences and 10 word sentences with an insertion in between the noun and verb. This suggests that the effect of length was mediated by the position of the insertion of the additional propositional phrase, a proposition that is supported by the significant interaction between sentence type and sentence complexity.
Response time results

A previous study by Wingfield, Peelle, and Grossman (2003) suggested that syntactically complex sentences produce diminished response accuracy and correspondingly slower reaction times when compared to their easier counterparts. These slower reaction times were shown by Cooke et al. (2001), who found that in reading complex sentences, responses were significantly longer as a result of increasing complexity. Based upon these findings, the present study hypothesized that manipulations of syntactic complexity in auditory sentences would show a similar pattern, however as the results section suggests, this was unsupported.

In Cooke et al.’s 2001 study, sentences were manipulated in a similar fashion to the present study, with added phrases (in their case, subordinate clauses in an antecedent gap) inserted into object and subject relative sentences. These researchers determined the earliest point at which an individual, acting with maximum efficiency, would be able to determine the agent of the action. We followed this procedure and measured response times from this point in each sentence. As Figure 2 shows, response times for 6-word sentences and 10-word long noun-verb gaps were as expected, with longer response times for the object relative rather than subject relative sentences. The 10 word short noun-verb gap sentences, however, showed a curiously reversed pattern.

Participants hearing these sentences showed slower response times for the subject relative than the object relative versions of the sentences. Furthermore, response times for the object relative sentences of this complexity were significantly faster than the object relative response times for the 6 and 10-word long noun-verb gap sentences respectively. Similarly, the subject relative response times of this type of sentence were significantly
higher than either of the other two complexities of sentences. Another notable result is the significantly shorter response times for subject relative 10-word long noun-verb gap when compared to the 6-word sentences. We posit that the cause of this is that participants hearing the longer sentences may have been able to ignore the additional phrases upon determining that they were irrelevant to the decision made, and thus did not show the expected effect of slowed responding. These findings do not support previous literature, and even disagree with the robust finding that subject relative sentences are easier and thus more rapidly comprehended than object relative sentences. For this reason, researchers have attempted to suggest several possible explanations for these results.

While all participants heard sentences recorded by the same voice, and spoken in a natural prosodic fashion, it is possible that the 10-word sentences with short noun-verb gaps were in some way spoken in a manner that gave participants a different way of responding to the sentences. While thought to be unlikely, researchers are aware that using auditory stimuli meant to resemble natural speech as much as possible can lead to some variation in responses. A second, and what researchers feel more likely, potential explanation for the unexpected results, is that participants were not responding at maximum performance, for these sentences. Response times for the subject and object relative 10 word short noun-verb phrases sentences were not significantly different, indicating that participants were listening to approximately the same amount of information in the sentence before responding, rather than responding immediately after being able to determine the agent of the action. It was thus possible that participants waited until they felt as though they had heard a substantial amount of information within
the sentence before responding. It is possible that participants felt as though they could only respond after hearing the majority of the sentence, and as subject relative 10 word short noun-verb gap sentences has a notably earlier point of understanding than did their object relative counterparts, this would then show itself in the form of the results seen. A final possible explanation for these results is that individuals were able to tune out or ignore the additional prepositional phrases that were, in the subject relative short noun-verb gap sentences, essentially irrelevant. As no questions were asked of the participants regarding the additional prepositional phrases it is not known if the results were merely a result of the selective attention of the participants as they performed the task.

**Future directions**

Prior to exploring the ultimate future directions of this research, I would like to propose additional measures and studies that might shed light on the cause of the unexpected latency measures for 10-word short gap sentences found in this study. In future versions of this study one might probe knowledge of the prepositional phrases to ensure that they were not being ignored as participants listened to the sentences.

In this study the effects of syntactic complexity, length, and length of the noun-verb gap were explored in young adults with good hearing. It is the goal of this research to provide a means of observing how these effects impact the responses of young adults with good hearing, providing a baseline comparison for future studies exploring the same effects on young adults with poor hearing, as well as older adults with good and poor hearing. Hearing impairment is a chronic medical condition that affects approximately 10 million Americans over the age of 65 (Stewart & Wingfield, 2009; Lethbridge-Ciejk et al., 2004). With the population of older adults growing each year, the importance of
understanding the impact of presbyscusis, age-related hearing loss, on cognitive processing is undeniable. One particularly noteworthy hindrance faced by older adult populations with extreme or even mild to moderate hearing loss is difficulty in understanding speech (Pichora-Fuller and Souza, 2003). As verbal communication is vital for typical daily functioning, difficulty due to auditory decline can hamper the daily activity of older adults drastically. Previous research has made great progress in exploring the effects of such hearing loss on specific aspects communication; particularly in regards to the effect it can have on memory and comprehension of auditory stimuli. However, further exploration of the effect hearing decline has on one’s ability to rapidly and correctly comprehend complex sentences is needed. The current research provides a method for further investigation into how hearing loss can impact sentence comprehension, while also exploring the effect of sentence complexity and length, and thus working memory and executive functioning.

It has been suggested that hearing loss puts an increased demand on cognitive resources that are typically necessary for encoding auditory stimuli, a concept known as the *effortfulness hypothesis* (Piquado et al., 2012; Baldwin & Ash, 2011; McCoy et al, 2005; Stewart & Wingfield, 2009; Rabbitt, 1991). At its basis, the hypothesis suggests that individuals with hearing loss must exert more effort than those with good hearing acuity in order to clearly perceive and process auditory stimuli. Due to this effect, individuals with poor hearing acuity are left with less available cognitive resources for encoding and processing the information, which has been seen to not only affect memory, but also one’s ability to successfully perform secondary tasks (Tun et al., 2009). The evidence supporting this strain on one’s ability to perform an unrelated secondary task
has serious implications for the daily lives of older adults suffering from hearing loss. As individuals are almost perpetually bombarded with verbal communication or auditory stimulation, older individuals with hearing loss are unable to escape the constant, additional demands on cognitive effort. This added strain could lead not only to general memory decline due to decreased resources for encoding information, but also potentially utilize resources needed to successfully perform other important tasks.

Difficulty with comprehension in older adult populations is not solely due to an inability to hear clearly. Age-related declines in working memory (Craik et al., 1990) and processing speed (Salthouse, 1996), in combination with hearing loss, can result in an increased amount of effort required to communicate. While it is possible to consider and study general cognitive decline quite separately from peripheral and central auditory processing, the levels of information processing are interconnected, and thus work in conjunction to exacerbate the effect on comprehension (Wingfield et al., 2005). As ‘hearing’ occurs in the periphery, and processing takes place in the central auditory systems, it is impossible to completely separate the effects of age-related cognitive decline and the effects of auditory decline. Thus, many comparative studies have been conducted with age-matched older adults who have similar age-related cognitive decline, but differ in hearing acuity. The interconnectedness of the systems of processing results in increased exertion required for peripheral auditory perception draining limited cognitive resources and ultimately reducing already limited and declining cognition (Wingfield et al., 2005). This is particularly notable in the impact on working memory resources necessary for speech comprehension, which has been shown to decline as a result of decreased hearing acuity (Piquado et al., 2012).
Consequently, a decline in hearing acuity paired with general slowing in processing can create a notable gap in rate and accuracy of sentence comprehension (Wingfield & Tun, 2001). This slowed processing speed paired with the rapid rate of presented stimuli strains older adults as they attempt to clearly hear individual words or phrases while attempting to comprehend conversations (Piquado et al., 2012). While young adults are able to utilize working memory rather effortlessly, older adults exhibiting working memory decline, as well as decreased attentional resources must exert greater effort to hold and organize information for comprehension. (Stewart and Wingfield, 2009; Craik and Byrd, 1982; Salthouse, 1994). The current study serves as a basis for studying the manipulations of syntactic complexity and working memory demands on this population of individuals suffering from hearing loss, and as such further research in this direction is a primary focus of this experiment.
References


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