

Investigating the Role of Action Representations in Sentence Comprehension

by

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B.A., University of Victoria, 2013

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of the Requirements for the Degree of

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Supervisory Committee

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Abstract

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The effect hand action representations have on language processing was investigated using eye-tracking techniques. Subjects were shown an image of a hand action and asked to hold the action in working memory while reading a sentence, which described an actor lifting, or using an object. The displayed hand actions were related to either a functional (using) or volumetric (lifting) interaction with an object that matched or did not match the object mentioned in the sentence. A neutral condition was also used which displayed a black circle instead of a hand action. No significant difference was found between any of the five working memory conditions for gaze duration, probability of word skipping, and several other dependent measures utilized in the study. A significant difference was found for gaze duration when the conditions were restricted. Shorter gaze duration was observed for the hand action congruent to both the context and the object mentioned in the sentence and longer gaze duration was observed for the hand action congruent to only the sentence context. Some possible explanations of the results are that subjects may not have encoded the hand actions as action representations, or that hand actions represented in working memory have no effect on sentence processing.

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Dedication

This work is dedicated to those who have instilled in me the value of education and work ethic.

My mother: for providing me with an incredibly strong and independent woman as a role model. You have shown me what it means to work hard and never give up.

My father: for being an unwavering source of support and acceptance. You have kept me moving forward on days where that seemed nearly impossible.

My sister: for teaching me to always be yourself and never to let others stop you from achieving what you want. You have given me someone to look up to.

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1. Introduction

It has been well established that during language comprehension mental representations of actions are evoked (Rueschemeyer, Lindemann, Rooij, van Dam, & Bekkering, 2009; Zwann & Taylor, 2006). Much of this evidence has come from neuroimaging and fMRI studies, which have shown that action words or nouns denoting manipulable objects lead to the evocation of mental representations (Kana, Blum, Ladden, & Ver Hoef, 2012). When subjects are exposed to these types of words activation occurs in somatotopically relevant areas of the motor cortex (Hauk, Johnsrude, & Pulvermüller, 2004). The activation of these mental representations is a phenomenon called motor resonance. This likely occurs each time a person encounters a goal directed action or phrase depicting a goal directed action (Uithol, Rooij, Bekkering, & Haselager, 2011).

A question resulting from these findings, is what is the mechanism behind the effects present in these neuroimaging studies? Motor resonance implies the presence of an association between activity in the premotor cortex and perceptual and language comprehension events, such as identifying objects and recognizing words (Bub, Masson, & Lin, 2013) but the role of these mental representations is unclear. Currently, two positions exist which aim to elucidate the purpose of mental representations.

The first position describing the role of mental representations claims that the activity found in the premotor cortex is serving a functional role in the identification of objects and words. This theory claims that mental representations are evoked as part of the comprehension process and the activation of the motor cortex is required in language processing (Barsalou, 2008; 2009). The mental representations evoked during the presentation of action language act as

mental simulations of the action being described which are necessary in order to comprehend the words being processed (Gallese, & Lakoff, 2005).

An alternative position attempting to explain the role of mental representations is in strong contrast to the theory that mental representations play a functional role in the comprehension process. Instead, this position theorizes that the mental representations do not play a functional role in comprehension but instead are a by-product of comprehension meaning that they occur as a consequence rather than as a cause of successful comprehension (Mahon, & Caramazza, 2008). This theory implies that during the processing of language, mental representations are automatically evoked and do not aid in comprehension.

Mental representation is a general term for any form of representation, whereas *action representation* is a more specific term used to describe mental representations of goal directed action. Therefore, for the remainder of this thesis the term action representation will be used to describe the representations being discussed.

To date the majority of research that has attempted to settle this issue has focused on how sentence processing can affect object recognition or motor movements (Markman, & Brendl, 2005; Glenberg, & Kaschak, 2002; Masson, Bub, & Lavelle, 2013; Bub, & Masson, 2012). In a study by Glenberg and Kaschak a sentence-action compatibility effect was found (2002). Subjects were faster to complete a movement when it was in the same direction as a movement depicted by a sentence they had just heard. The study indicates an embodied view of cognition as the findings suggest that the phrases being used are creating representations of the actions being described which are in turn priming for the same direction of movement to take place and affecting the participant's movements. Other studies, such as those by Masson et al. and Bub and Masson have studied how listening to an auditory sentence can affect reach and grasp times.

These behavioural studies found that subjects were faster to make a cued reach and grasp action if the action was compatible with a word or action mentioned in the sentence they had just heard. These results indicate that processing of action language creates action representations of the action or manipulable object and that these action representations are recruited in coordinating motor movement.

Although fMRI and behavioural studies have provided evidence for embodied cognition they are limited in their interpretation since they do not investigate whether language processing is affected by action representations. These studies allow the inference to be made that the cognitive processes taking place, such as the creation of action representations for actions described by language, have affected the action taking place, for instance reaching toward or away from the body, but not whether actions have the ability to influence cognitive process. That is, could action representations occur from movements or stimuli depicting action and in turn modulate cognitive processes such as language comprehension (Yee et al., 2013). In order to provide strong evidence that action representations play a causal role in language comprehension it is necessary to investigate whether activating these action representations will modulate language processing (Anderson & Spivey, 2009). Thus, the current study investigates whether a hand action held in working memory can modulate sentence processing.

The objective of this paper was to elucidate the role of action representations in language processing. To date, much of the research involving embodied cognition has focused on how the semantic priming of words can affect behavioral responses. That is, much of the research conducted has focused on how processing words can affect a person's bodily state. In order to conduct a deeper investigation of embodied cognition the effect of action representations on sentence processing needed to be investigated. This research would be able to provide evidence

as to whether actions can affect comprehension by investigating whether sentence reading is affected by actions held in working memory.

To provide a detailed account of sentence processing the current experiment utilizes eye-tracking techniques. Past research involving eye movements have shown that fixations tend to occur on stimuli that are congruent with current mental operations, providing researchers with information about the time course of mental processes during language comprehension (Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995). Furthermore, research has shown that fixations times are quickly affected by lexical influences, indicating that language processing produces rapid control over eye fixations (Reingold, Reichle, Glaholt, & Sheridan, 2012; Sheridan & Reingold, 2012).

Recent eye tracking research has also produced evidence that action representations are evoked during language comprehension. In a study by Heard, Masson, and Bub (in press) subjects listened to sentences describing an actor manipulating an object while viewing a display containing four hand actions. The subject's task was to select the hand action described in the sentence. Heard et al. found that subjects gazed more frequently at hand actions congruent with the type of action described in the sentence as soon as it was mentioned. These results are unsurprising given that the subject's task was to select the matching hand posture. The result of interest, however, was that there was some tendency to look at the object-relevant action that did not match the stated action, implying an automatic activation of action representations.

The purpose of Experiment 1 was to demonstrate whether language comprehension is modulated by action representations held in working memory. This was done using eye tracking measures to provide a detailed account of how the sentences were being processed. Subjects were asked to hold a hand action in working memory while reading a sentence depicting an actor

interacting with a manipulable object. The objects included in the sentences could either be manipulated for the purpose of using them (functional) or lifting them (volumetric) and sentences could depict either one of these action types. For example:

(1) Mark used the TV remote to turn down the volume

(2) Jane lifted the hairspray so no one would trip on it

Randomly after a subject read a sentence they would be required to answer a yes/no question about the sentence or to pantomime the hand action being held in working memory. The hand action held in working memory came from one of four conditions. One pair of actions was relevant to the object and the other pair was irrelevant. From the pair relevant to the object one hand action was also relevant to the action described in the sentence. A neutral condition was also included which required no working memory load.

Eye tracking allowed for many dependent measures to be used. The dependent measures used in the current study were: gaze duration, first fixation duration, probability of skipping a word, probability of returning to a word, saccade length, and pupil size. Gaze duration refers to the length of time spent looking at a particular word. Any saccade to a new fixation within the same interest area was included in the total for gaze duration. Increased gaze duration is associated with processing a word as research has shown that the eyes tend to fixate on stimuli that are congruent with current mental operations (Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995). The measure is affected by the predictability of a word as well as the frequency of the word (Rayner, 1998). If subjects were holding a congruent hand action in working memory the object and verb would be predictable therefore might cause a decrease in fixation time when compared to holding a hand action in working memory that was not congruent with the sentence being read.

The dependent measure first fixation was operationally defined as the length of time spent fixating on a word for the first time. First fixation is related to the lexical access of a word, meaning how difficult the word is for the subject to process or comprehend (Rayner & Duffy, 1986). The measure was included, as it would provide information about whether a subject's primary fixation on a word would be affected by their working memory load. Past research has shown that context modulates first fixation duration. For example, words that are unexpected have longer first fixations (Sheridan & Reingold, 2012). Since first fixation reflects the ease of encoding then it is expected that an additional working memory load could also modulate fixation duration.

The probability of word skipping and probability of returning to a word were defined as the likelihood of skipping a word entirely or returning to a word after having already fixated on it and moved on to a later word. These measures would also allow for the investigation of how the working memory load would affect sentence processing. It was hypothesized that congruency might lead to more fluent, or conflict free processing of the verb and especially the object noun because the action representation held in working memory may prime the processing of the words. The probability of returning to a word is influenced in a similar manner by what is taking place cognitively. Returning to fixate on a word may also be modulated by the level of conflict between the hand action held in working memory and the action depicted in the sentence. A low probability of returning to a word may be present for the object and verb when a congruent hand action is held in working memory as the processing of the word is not conflicting with the hand action being held in memory.

Saccade length was operationally defined as the length of a saccade away from a particular word. This dependent measure was included, as it would provide information about the

order in which subjects were processing the words and if large saccades were being made away from particular words depending on the working memory load being held. For instance, if a word is processed more easily because of its congruency with the hand action, then a subject may be able to carry out more parafoveal processing, which is the processing of words near (in the parafovea of) the word currently being fixated. For a word that is more efficiently processed resources may be available for processing words in parafovea, particularly to the right of the fixated word. More parafoveal processing would lead to longer saccades since the words surrounding the word being viewed have already been processed (Schotter, Angele, & Rayner, 2012). Finally, pupil size was defined as the diameter of the pupil while viewing a word. Pupil size was included because an increase in pupil size has been linked to an increase in working memory load (Kahneman, & Beatty, 1966; Attar, Schneps, & Pomplun, 2013). It was hypothesized that holding a hand action in working memory which is congruent with the sentence being read would have a smaller cognitive load than holding a hand action which was incongruent. Thus, it was expected that pupil size would be smaller for congruent working memory conditions than for incongruent conditions.

This methodology allows the processing of each individual word to be investigated as well as the processing of the sentence as a whole (Just, & Carpenter, 1980). However, a limitation of using this method is that it depends on the assumption that the subject is encoding the hand image presented to them as an action representation. All of the dependent measures utilized in this experiment serve the purpose of capturing any differences that may occur in sentence processing due the relationship between the hand action being held in working memory and the sentence being read. The cost of this technique is that it rests on the assumption that subjects will encode the hand images being presented as action representations. Past research has

shown that visual, action, and spatial stimuli use different working memory mechanisms (Wood, 2007) and thus action representations are entirely different from visual images. If the hand images presented are not sufficient to cause action representations to be formed then the eye tracking techniques are not measuring the modulation of sentence processing due to action representations but instead some other working memory load.

2. Experiment 1

The objective of Experiment 1 was to establish how a hand action held in working memory would affect the processing of a sentence. The sentence depicted an actor performing an action, which was either congruent or incongruent with the hand action. The hand action displayed was either functional (using) or volumetric (lifting) and was either congruent or incongruent with the object mentioned in the sentence. A fifth working memory condition was included in which a black circle was displayed. This was labeled as the neutral condition, and was included to investigate whether a difference in sentence processing would occur when a subject held no working memory load. Gaze duration, first fixation, probability of skipping a word, probability of returning to a word, the length of saccade movement, and pupil size were investigated as a function of working memory load, defined as the relationship between the hand action in working memory and the sentence with which it was paired. Functional and volumetric sentences were used as a within-subject manipulation and structuring of the sentences was varied to place the goal of the action at either the beginning or end of the sentence (distal goal first and distal goal second). The change in structuring was a between-subject manipulation. The two different sentence structures were used based on results found in a study conducted by Masson, Bub, and Lavelle (2013). The study found that whether the distal goal was mentioned first or second in the sentence had different effects on the priming of functional and volumetric grasps. Of particular interest was the gaze duration on the object noun. A decrease in gaze duration for the object noun on sentences which are congruent with their paired hand action would indicate that subjects have an action representation of the hand action which is modulating the processing of the sentence. An increase in gaze duration for the object noun interest area in cases where the

sentence was incongruent with the hand action would also indicate that subjects are creating action representations of the hand actions and that an incongruent action representation could cause conflict when processing the sentence. It was hypothesized that congruent working memory conditions would display higher probability of skipping a word and lower probability of returning to a word as the hand action held in working memory may facilitate the comprehension of a sentence which matched its action. It was also hypothesized that first fixation duration and pupil size would be larger in conditions where the hand action held in working memory did not match the action described in the sentence. In addition, it was believed that congruent working memory conditions would result in a higher percentage of correct comprehension and pantomime responses as the hand action held in working memory would be reinforced by the action read in the sentence and vice versa.

2.1 Method

2.1.1 Subjects

Sixty students at the University of Victoria were tested. All subjects were native English speakers and received extra credit in an undergraduate Psychology course for their participation.

2.1.2 Materials

Twelve object names were selected for use in Experiment 1. The twelve objects afforded three functional and three volumetric hand actions, which are displayed in Table 1 with their associated object names. Photographs of male hands posed in the six hand actions were taken and rendered as digital gray-scale images. Figure 1 shows an example of a hand action image. A black disk was also used as a neutral stimulus in the control condition. These images were displayed on screen for a brief period of time before the appearance of a sentence. Each of the

hand actions was displayed equally often prior to a sentence. Each hand action display measured 7.50° of visual angle both horizontally and vertically when presented on the monitor viewed by the subject. The average visual angle of each character in the sentences displayed was 0.32° .



Figure 1. An example of a hand action displayed to subjects. The hand displayed is the functional action of a spray grip.

A set of 240 sentences was constructed, half describing a functional interaction with an object and the other half describing a volumetric interaction. The sentences were constructed so that the actor was mentioned first, followed by a functional (e.g., *used*) or volumetric (e.g., *lifted*) verb, the name of a manipulable object, and finally a clause elaborating the purpose of the action (distal goal). Sentences that state the distal goal at the end of the sentence are henceforth referred to as DG2. A second version of each sentence was constructed by moving the final clause (distal goal) to the beginning of the sentence. These sentences are henceforth referred to as DG1 and an additional phrase was added to the end of them to ensure the object noun was not the last word.

For example:

(1) The little girl lifted the marker to show it to her mother.

(2) To show it to her mother the little girl lifted the marker because she loved the color

Thirty subjects were presented with DG1 sentences and thirty were presented with DG2 sentences. Each of the 12 objects listed in Table 1 was used in 10 sentences for each of the volumetric and functional interactions. A yes/no comprehension question was written for 60 randomly selected sentences. The questions were used to encourage subjects to attend to the sentences in a meaningful way. For example, the sentence, “*Peter lifted the pen to write a letter*” was paired with the question, “*Was Peter writing a book?*” Another 60 randomly selected sentences were followed by a prompt to pantomime the hand action the subject was holding in working memory. This was done to ensure the subjects were attending to the hand actions being displayed.

Table 1. Hand Actions and Associated Object Names Used in Experiment 1 and Experiment 2.

| Functional action | Volumetric action | Associated object names |
|-------------------|-------------------|---|
| Pencil grip | Horizontal pinch | Crayon, marker, pen, pencil |
| Spray grip | Vertical grasp | Hair spray, insect spray, room spray, spray paint |
| Thumb grip | Horizontal grasp | Cellphone, Gameboy, iPod, television remote |

The order in which the sentences were presented was randomized and the sentences were paired equally often with each type of hand action across conditions. This resulted in five classifications of hand actions: functional congruent, functional incongruent, volumetric congruent, volumetric incongruent, and neutral. Functional and volumetric refer to the type of hand action and congruent and incongruent refer to whether the hand action matched the object noun utilized in the sentence. Neutral refers to trials where the black disk appeared and no hand action was displayed. The subjects’ task was to read the sentence while remembering the hand

action they were shown previously and to mimic the hand action or answer a comprehension question if prompted.

2.1.3 Procedure

Subjects were tested in a quiet room equipped with an SR Research Eyelink 1000 tower-mount eye tracking system. Only the eye position from one eye was recorded at a rate of 1000 times per second, although the subject viewed the display binocularly. The tower mount stabilized the position of the subject's head through use of a chin and forehead rest. A Cedrus response box was placed in front of the subject who placed their index fingers on the left and right-most buttons on the box. Stimuli were presented to the subject on an LED monitor 80 cm from the subject. A Macintosh Intel G3 computer controlled the presentation of the visual stimuli and a Dell computer recorded eye fixation data.

The subject's gaze was calibrated at the outset of the experiment as well as after any movement during rest breaks and at the conclusion of the experiment. To accomplish this, subjects fixated on nine points arranged in a 3 x 3 grid extending across the viewing area of the monitor. In Experiment 1 subjects were told they would be shown an image of a hand action followed by a sentence. The subject was instructed to hold the hand action in memory while reading the sentence and to answer a comprehension or pantomime prompt if it appeared at the end of the trial. An image of each of the hand action images and an example sentence and comprehension question were given during the instructions. On 60 of the 240 trials (25%) a comprehension question was asked after the sentence and subjects were asked to press the right-most button for a yes response and the left-most button for no. On another 60 trials (25%) a report prompt appeared on the screen after the sentence and subjects held up their dominant hand

to pantomime the hand action they had seen prior to the sentence. The order of the trials was presented randomly and after every block of 60 trials a rest break was offered.

Trials began with a fixation cross which was replaced by either the image of a hand action or the image a black circle for 1000 ms. This was followed by a 500-ms blank and then a fixation cross on the left side of the screen, which disappeared once the subject's gaze hit it. The left fixation cross was used to ensure that the subject's gaze was located at the beginning of the sentence when reading began. The sentence then appeared on the screen and remained on screen until the subject had finished reading and pressed either the right or left-most button on the Cedrus response box. After making the button response either a 1000-ms blank screen appeared or one of the comprehension or pantomime prompts. If the subject was prompted to pantomime the hand action, the researcher marked the trial as correct, incorrect, or spoiled and the next trial began. If a comprehension question appeared a new trial began after the subject made a button response and if a blank screen appeared it was automatically followed by a new trial.

2.1.4 Data analysis

The mean reading time for each sentence, comprehension question accuracy, and pantomime accuracy were recorded. For mean reading time, any sentence with a reading time of less than 100ms or over 12000ms was excluded from the analysis. These cut-offs resulted in 0.446% of the data being excluded.

Boundaries were chosen to divide the sentences into the following seven interest areas: actor, verb, "the", object, and the first, second, and third word after the object noun (word one, word two, and word three) were used for DG2 sentences. DG1 sentences had the following boundaries: the last word of the opening phrase (last word), actor, verb, "the", object, and the first and second word following the object noun (word one and word two). For example:

(3) The old woman/ picked up/ the/ cellphone/ to/ phone/ home

(4) To phone home/ the old woman/ picked up/ the/ cellphone/ because/ she needed a ride

Using the eye-tracking data gathered from the EyeLink 1000 system the gaze duration, first fixation, probability of word skipping, probability of return, pupil size, and saccade length were determined for each of the five hand action categories in each of the interest areas. Gaze duration is defined as the sum of all fixations in a particular interest area before the gaze moves out of that interest area. For example if a subject's gaze is on the object noun then moves to a new location still within the boundaries of the object noun both of those fixations would be summed into one gaze duration for the object noun. First fixation is the duration spent fixating in an interest area for the first time and probability of word skipping is the likelihood of skipping a particular interest area. Probability of return is the likelihood that a subject's gaze will return to a particular interest area, pupil size is the size of the subject's pupil in a particular interest area, and finally, saccade length is the length of the eye movement away from an interest area.

2.2 Results

The mean accuracy when answering the comprehension questions was 91.28% and the mean accuracy when responding to the pantomime prompts was 90.98%. These results indicate that subjects were attending to both the hand action displays as well as the sentences. Eye-fixation data from trials where a response error occurred were excluded from our analysis. For each of the analyses the mean was plotted for each hand action condition (functional congruent, functional incongruent, volumetric congruent, volumetric incongruent, and neutral) for functional and volumetric sentences and for DG1 and second separately. Error bars were computed separately for each sentence segment and represent 95% within-subject confidence intervals. In order to interpret the patterns of means, I used confidence intervals for the most part

rather than relying on significance tests (e.g., Loftus, 1996; Loftus, 2002; Loftus & Masson, 1994). For those who prefer null hypothesis significance tests, pairs of means within an interest area that are separated by at least $\sqrt{2}$ times the size of one arm of a confidence interval (i.e., confidence intervals overlap by no more than about 50%) are significantly different at $p < .05$ (Loftus & Masson, 1994). Also, the confidence intervals were computed by using the mean squared error for each interest area, which was determined by running separate ANOVA analyses. The results of the ANOVA analyses also failed to yield any significant results.

The gaze duration for DG1 sentences can be viewed in Figure 2. The pattern of gaze duration is similar for both functional and volumetric sentences. No significant difference was found between the working memory conditions for either sentence type. A similar pattern is present in Figure 3 for DG2 sentences

Figure 4 displays the probability of skipping an interest area entirely for DG1 sentences. For both functional and volumetric sentences the interest areas most likely to be skipped are “the”, and the second word after the object noun. In the case for DG2 sentences, which are displayed in Figure 5 a high probability of skipping is found for the interest areas: “the”, the first word after the object noun, and the third word after the object noun. The final three interest areas exhibited high skipping rates, especially the first word after the noun. It is worth noting that the first several words after the noun were often prepositions, which may have made them more likely to be skipped. Although “the” was the most commonly skipped word, task imperative words such as the object noun, actor, and verb have skipping probabilities of approximately 30 percent.

The first fixation duration for a word is presented for DG1 sentences in Figure 6 and for DG2 sentences in Figure 7. As with gaze duration, and the probability of skipping a word, there was no significant difference found between any of the five working memory conditions.

Including five working memory conditions in the computation of the confidence intervals may have introduced a large amount of variability. To reduce variability in the gaze duration and first fixation analyses the working memory conditions were restricted to only the key conditions of interest and aggregated across DG1 and DG2 sentences. (e.g., functional congruent and functional incongruent for functional sentences). The results of the restricted gaze duration analyses are displayed in Figure 8 and the restricted first fixation analyses are presented in Figure 9. Restricting the hand classes yielded a significant difference in gaze duration between the congruent and the incongruent working memory conditions when aggregating across functional and volumetric sentences $F(1,59) = 4.431, p = < .05$, although no effect was found for first fixation.

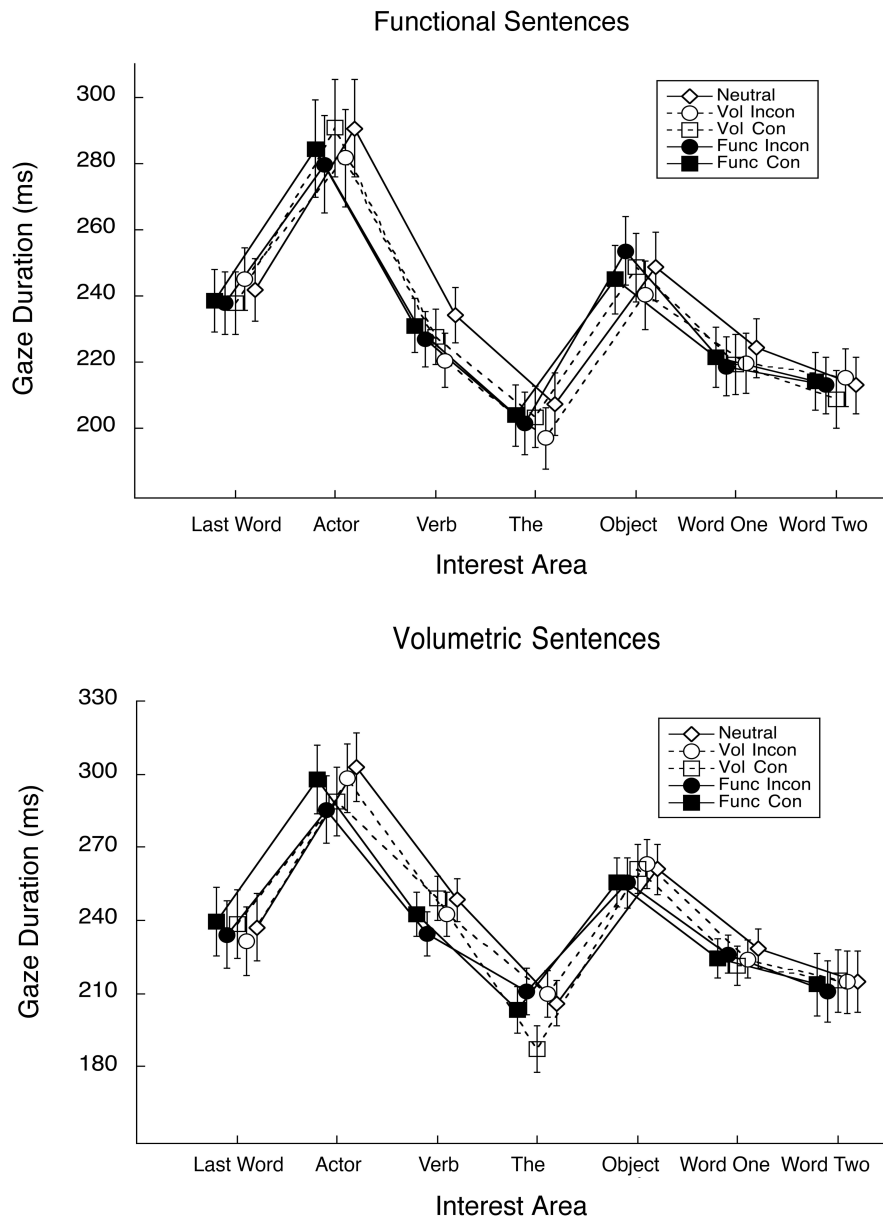


Figure 2. Gaze duration associated with each working memory condition as a function of sentence type (functional and volumetric) and interest area. These data are for DG1 sentences. Data points within each segment are staggered for visual clarity. Error bars are 95% within-subject confidence intervals computed separately for each sentence segment and are appropriate for comparing means within each segment (Loftus & Masson, 1994; Masson & Loftus, 2003).

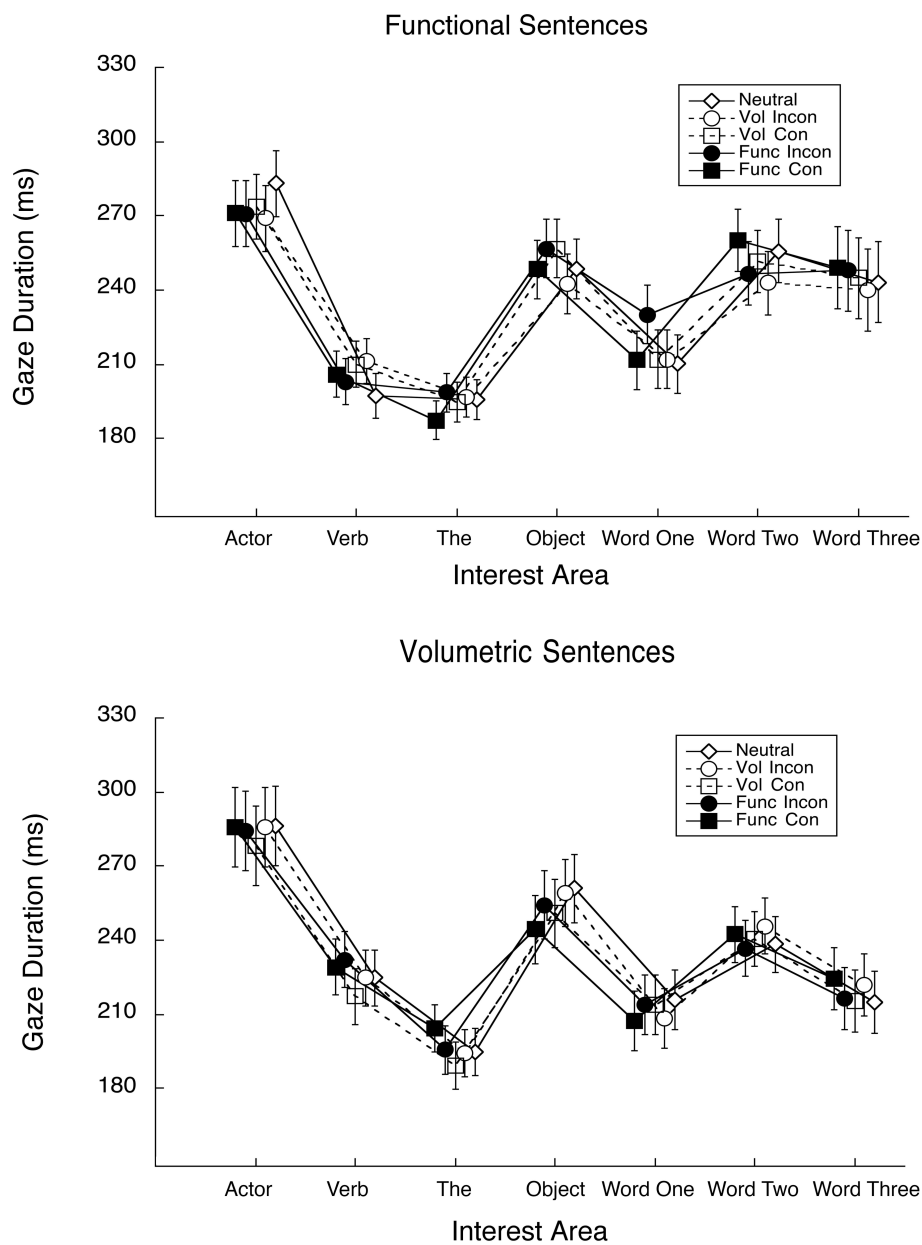


Figure 3. Gaze duration associated with each working memory condition as a function of sentence type (functional and volumetric) and interest area. These data are for DG2 sentences. Data points within each segment are staggered for visual clarity.

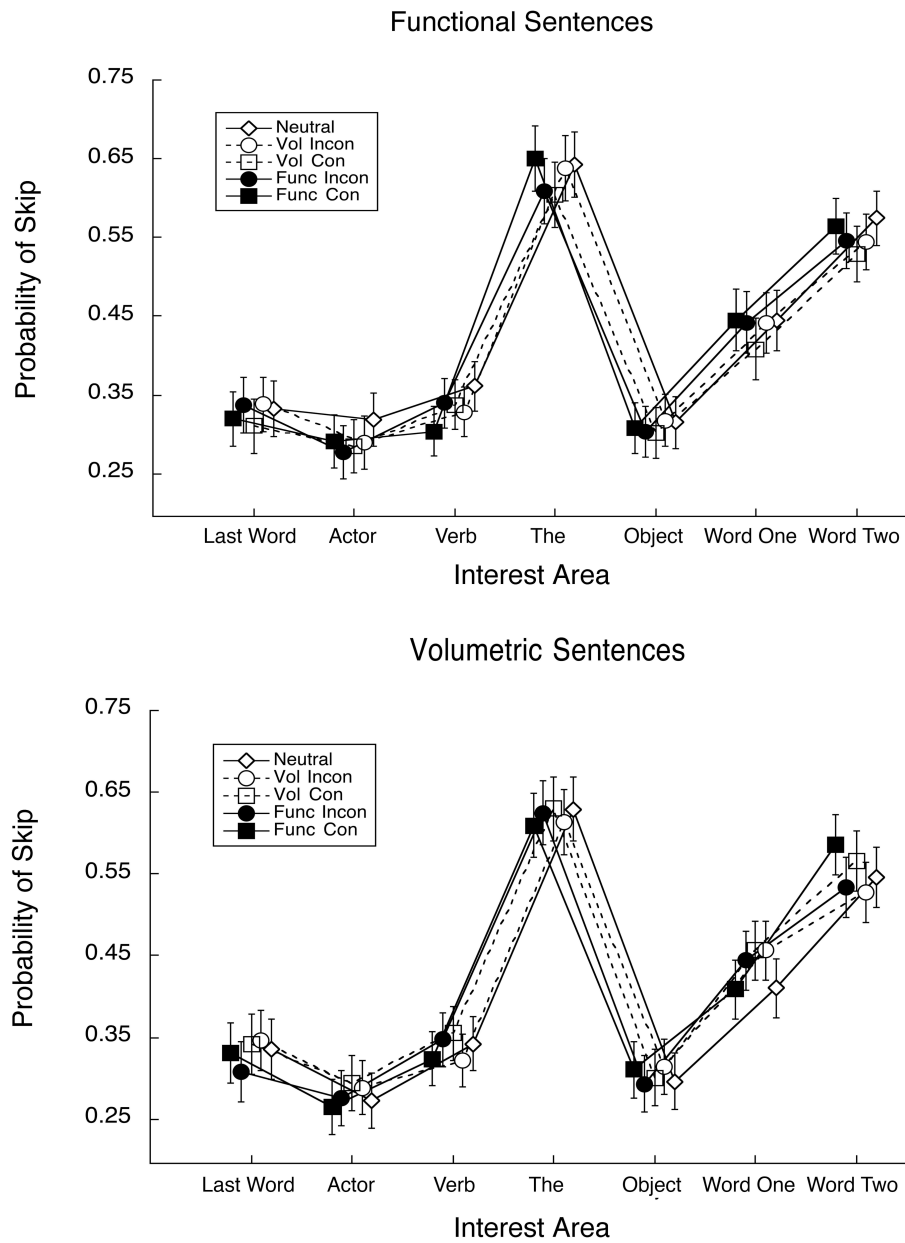


Figure 4. The probability of skipping a word associated with each working memory condition as a function of sentence type (functional and volumetric) and interest area. These data are for DG1 sentences. Data points within each segment are staggered for visual clarity.

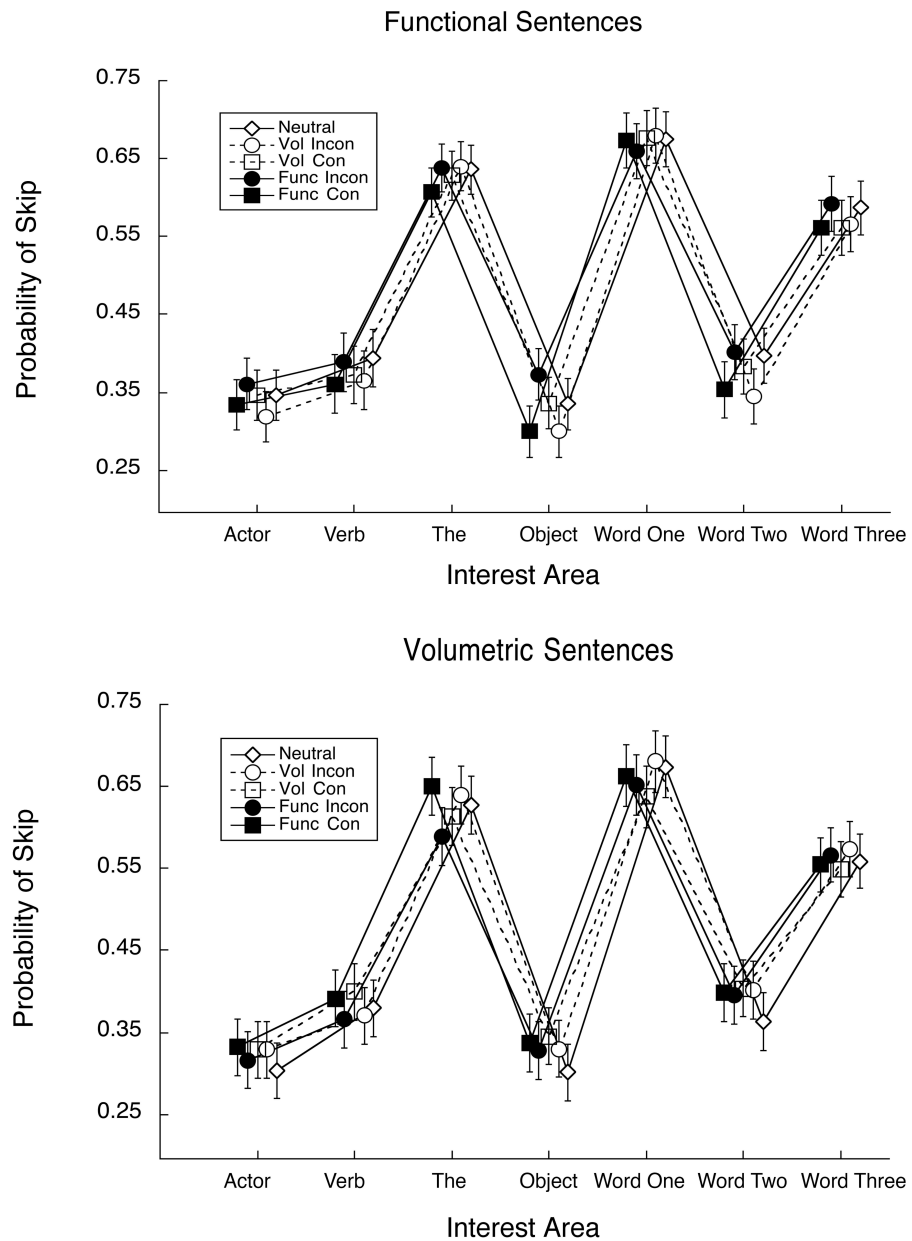


Figure 5. The probability of skipping a word associated with each working memory condition as a function of sentence type (functional and volumetric) and interest area. These data are for DG2 sentences. Data points within each segment are staggered for visual clarity.

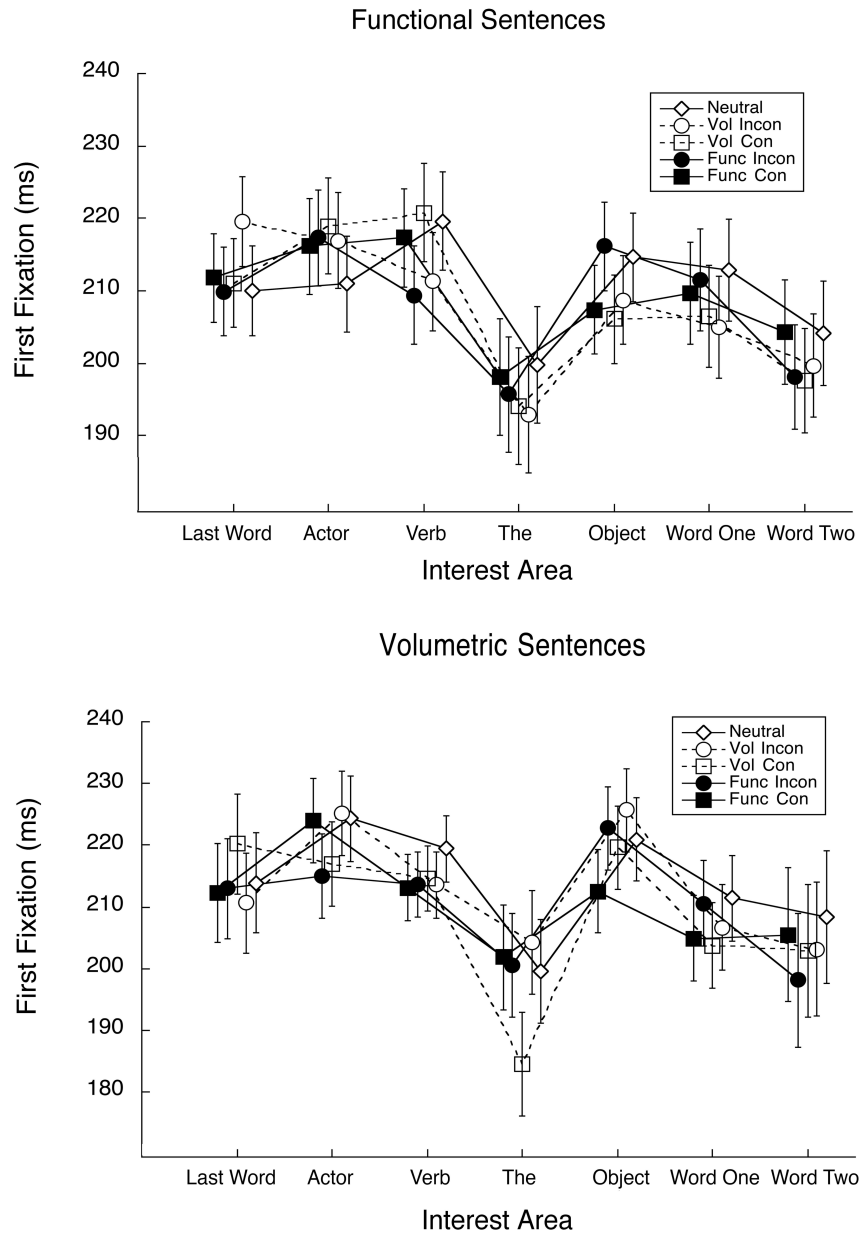


Figure 6. First fixation duration associated with each working memory condition as a function of sentence type (functional and volumetric) and interest area. These data are for DG1 sentences.

Data points within each segment are staggered for visual clarity.

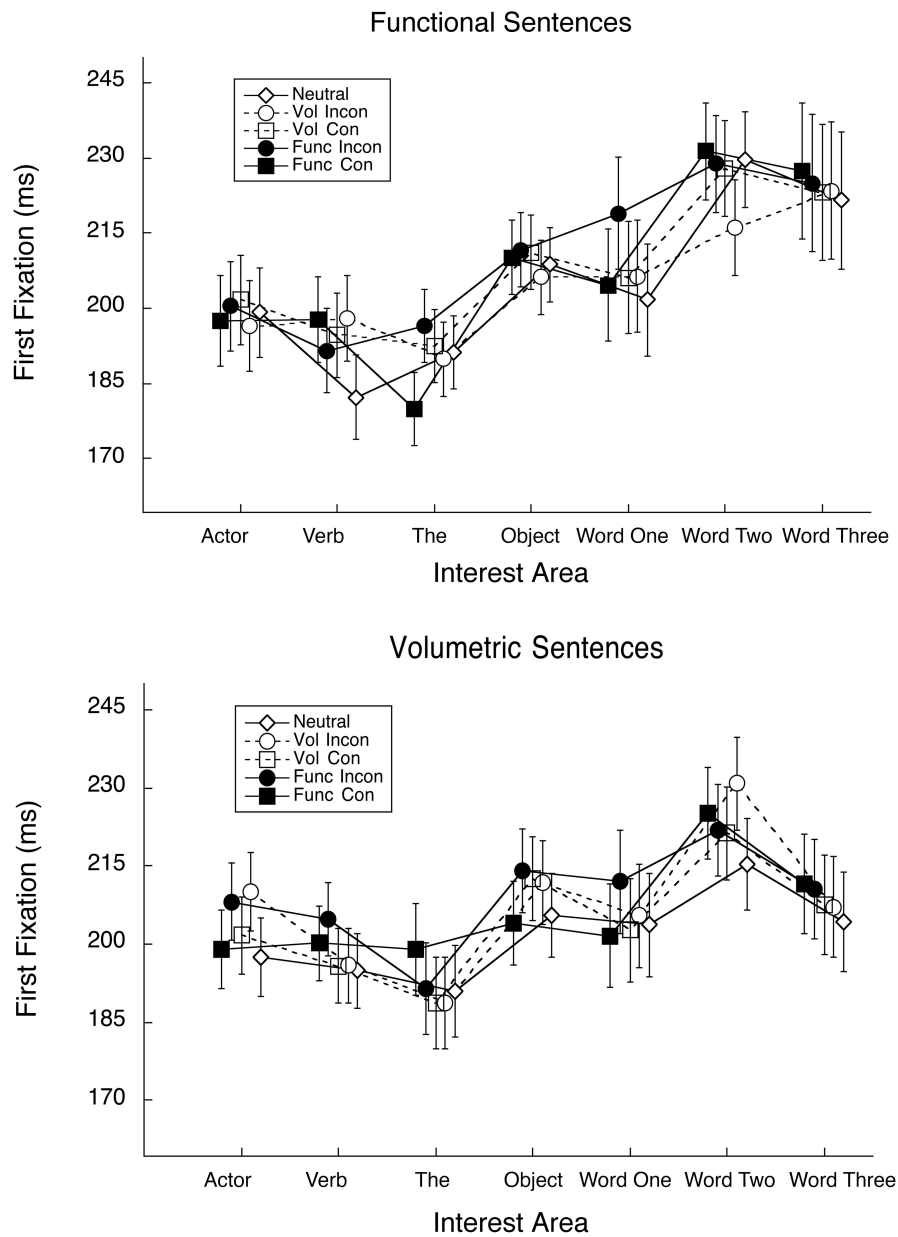


Figure 7. First fixation duration associated with each working memory condition as a function of sentence type (functional and volumetric) and interest area. These data are for DG2 sentences. Data points within each segment are staggered for visual clarity.

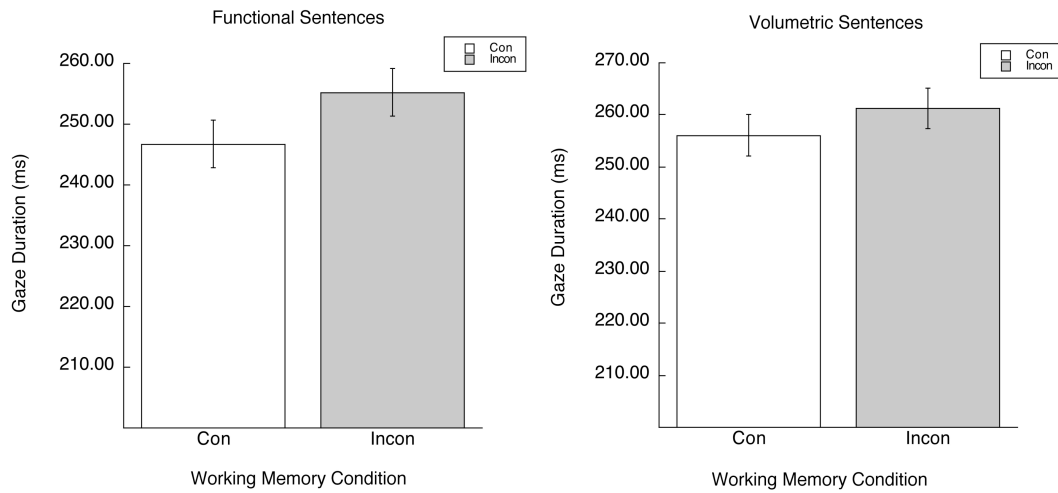


Figure 8. Gaze duration associated with each context relevant working memory condition for functional and volumetric sentences. These data are aggregated across DG1 and DG2 sentences.

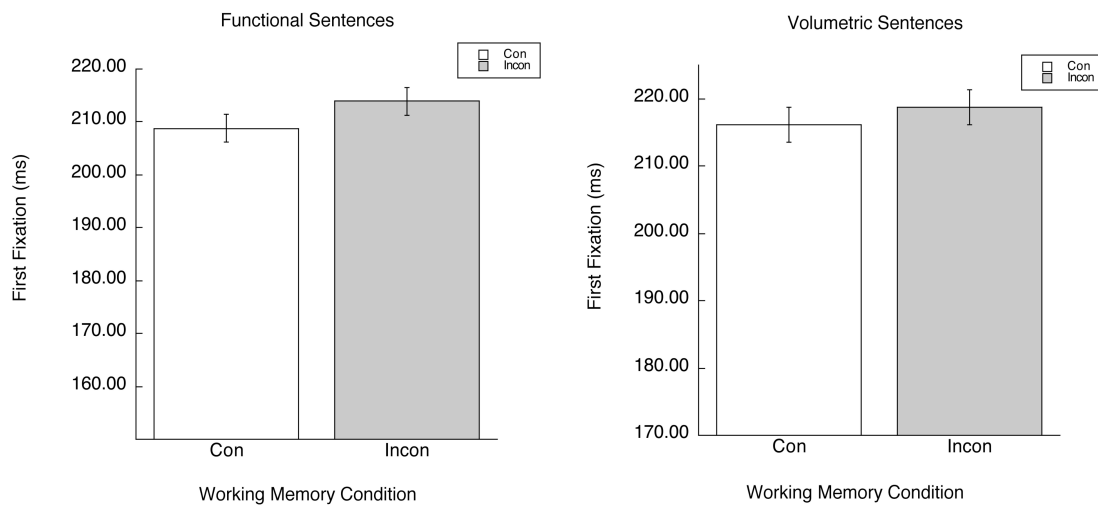


Figure 9. First fixation duration associated with each context relevant working memory condition for functional and volumetric sentences. These data are aggregated across DG1 and DG2 sentences.

Mean reading time is displayed in Figure 10 for DG1 sentences and Figure 11 for DG2 sentences. Reading time was significantly longer for DG1 than DG2 sentences but this is most likely due to the extra clause added to the end of the DG1 sentences. Figures 12 and 13 show the percentage of correct answers on pantomiming the hand gestures and Figures 14 and 15 displays the percentage of correct responses to the comprehension questions. Comprehension accuracy for the neutral condition is significantly higher than the other working memory conditions. However, the reading time for the neutral condition is also significantly higher, indicating a trade off between reading speed and accuracy.

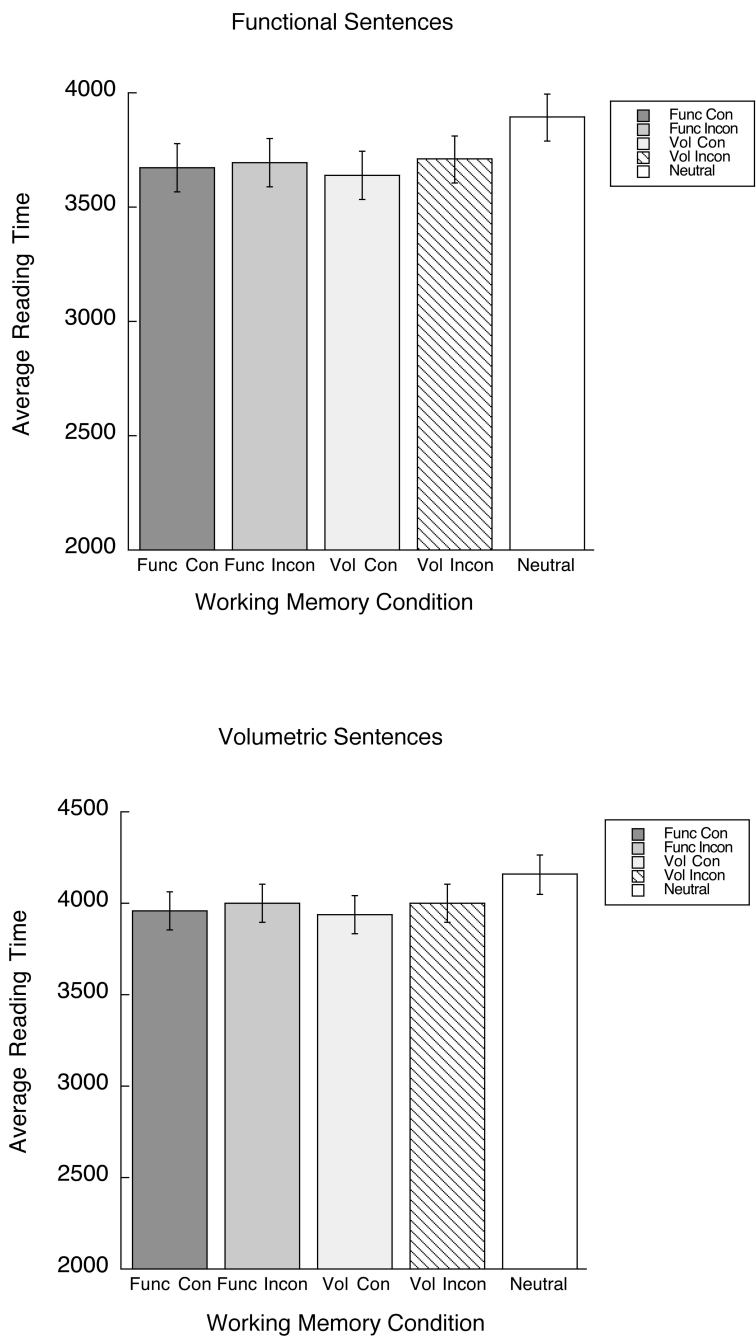


Figure 10. The mean reading time associated with each working memory condition as a function of sentence type (functional and volumetric). These data are for DG1 sentences.

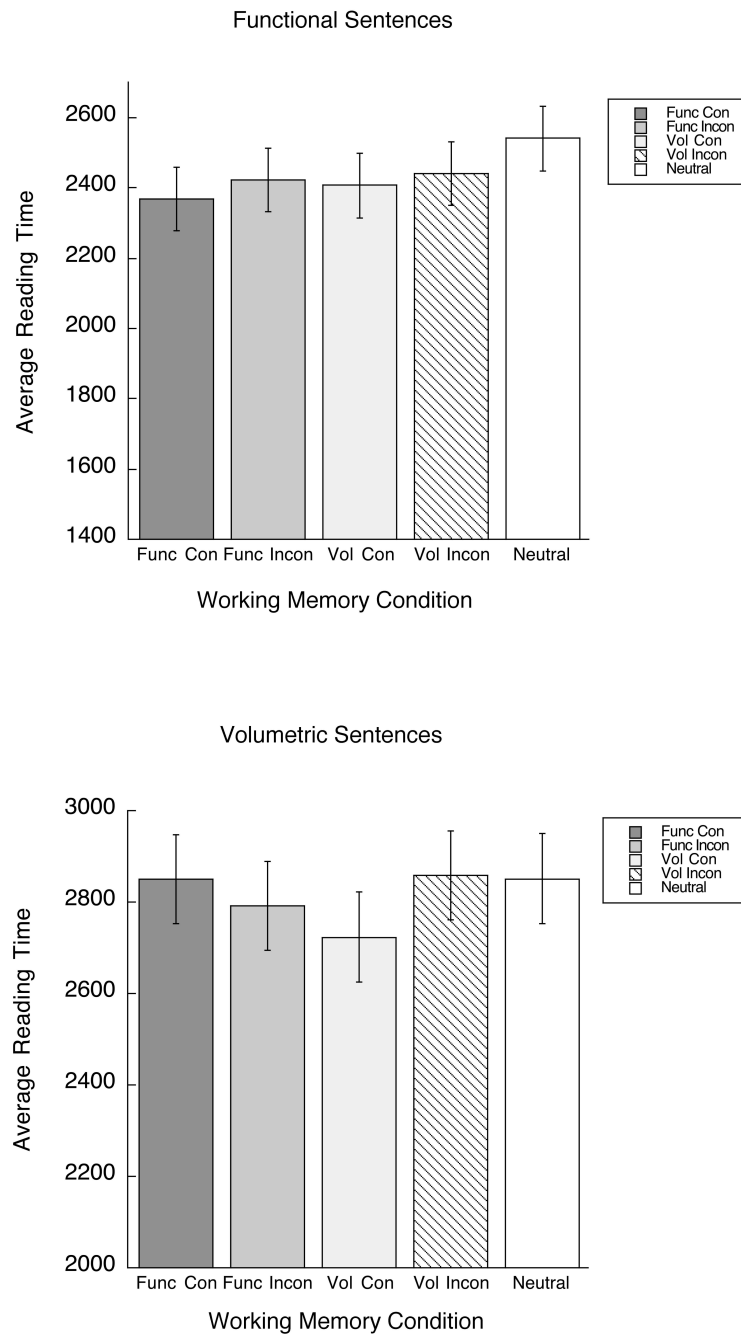


Figure 11. The mean reading time associated with each working memory condition as a function of sentence type (functional and volumetric). These data are for DG2 sentences.

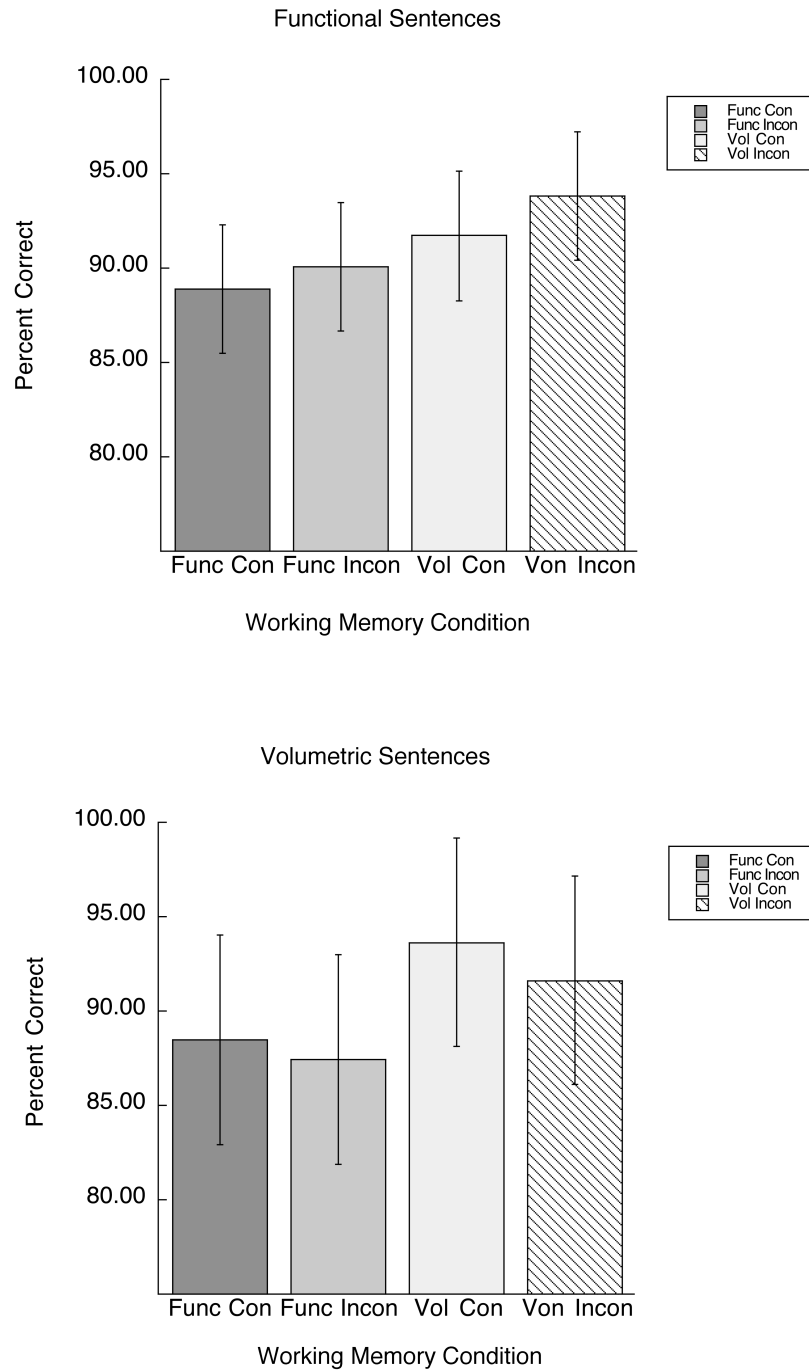


Figure 12. The mean percent of correct responses to pantomime prompts associated with each working memory condition as a function of sentence type (functional and volumetric). These data are for DG1 sentences.

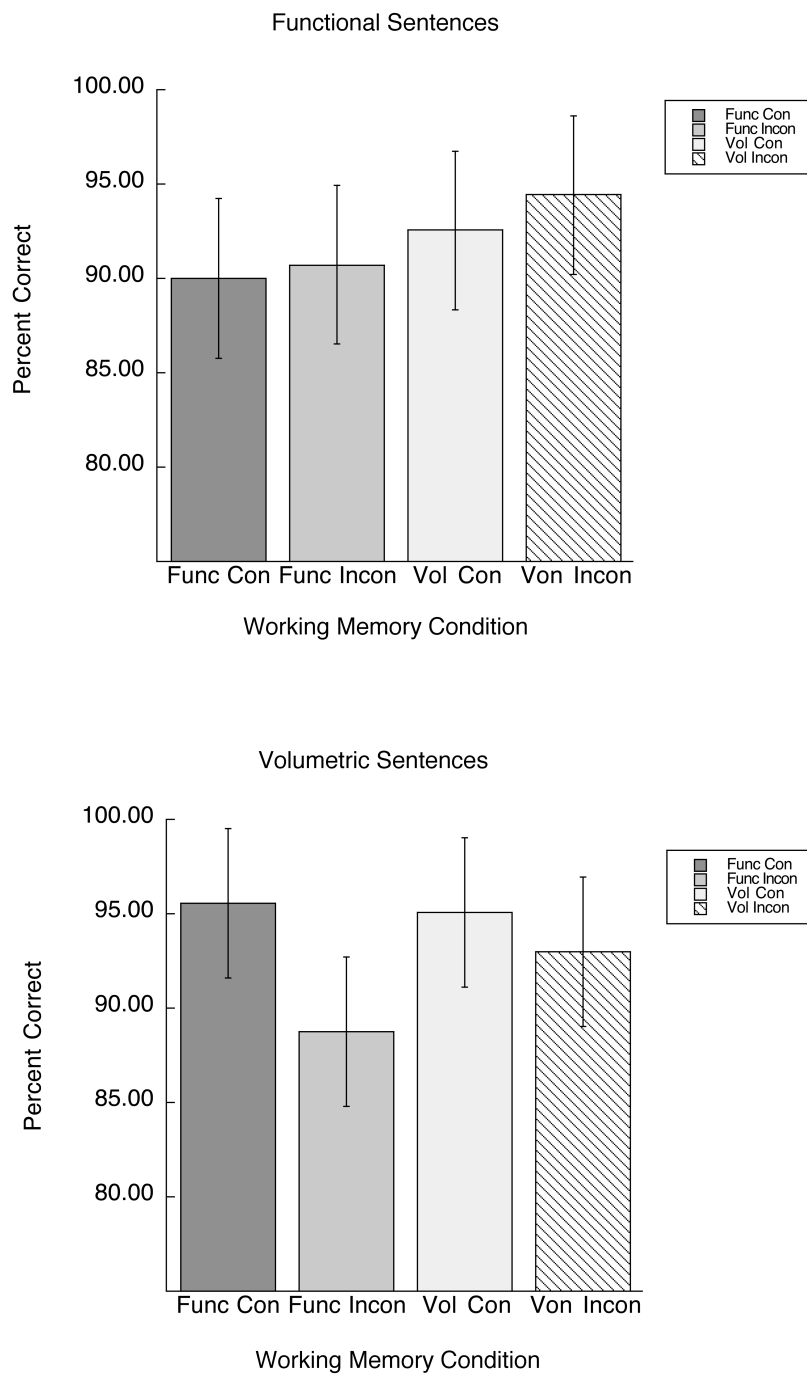


Figure 13. The mean percent of correct responses to pantomime prompts associated with each working memory condition as a function of sentence type (functional and volumetric). These data are for DG2 sentences.

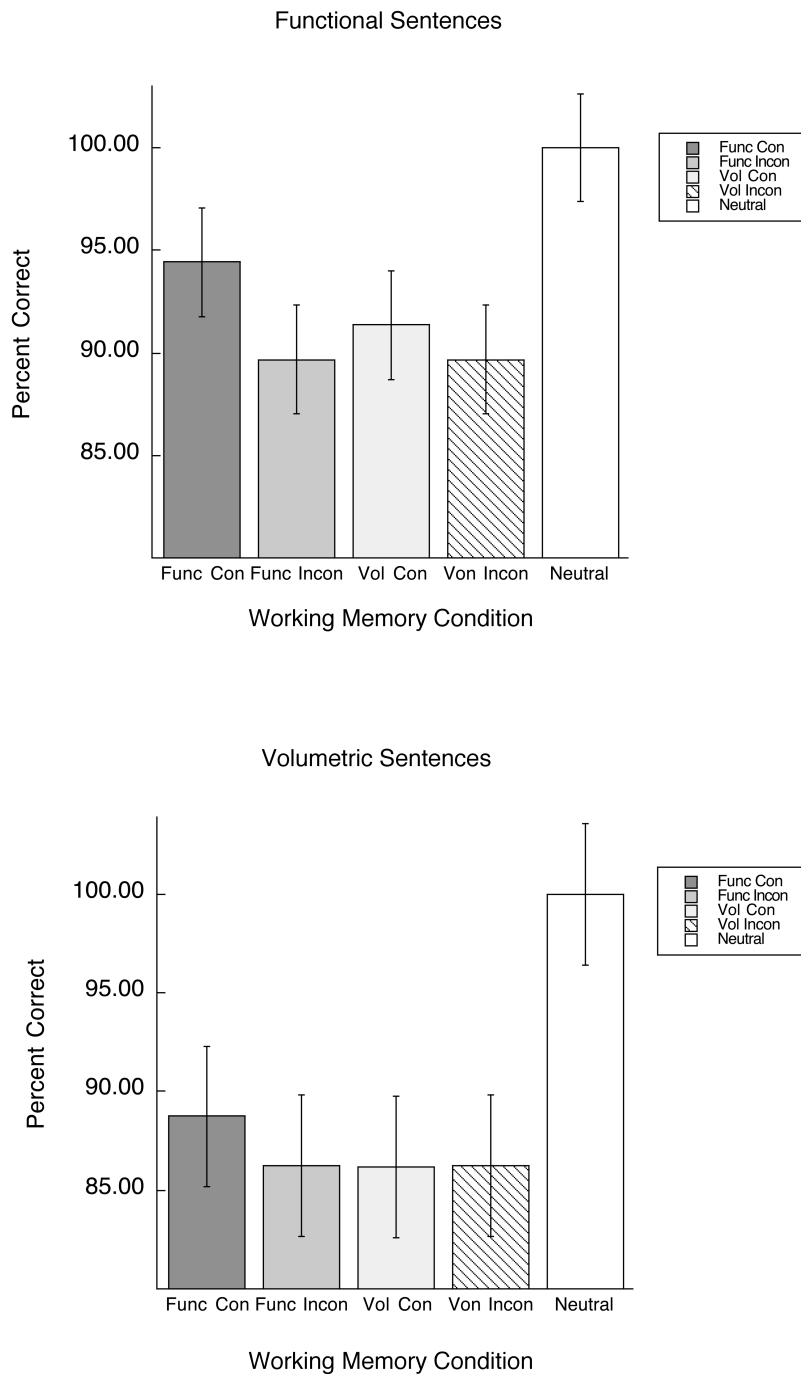


Figure 14. The mean percent of correct responses to comprehension questions associated with each working memory condition as a function of sentence type (functional and volumetric).

These data are for DG1 sentences.

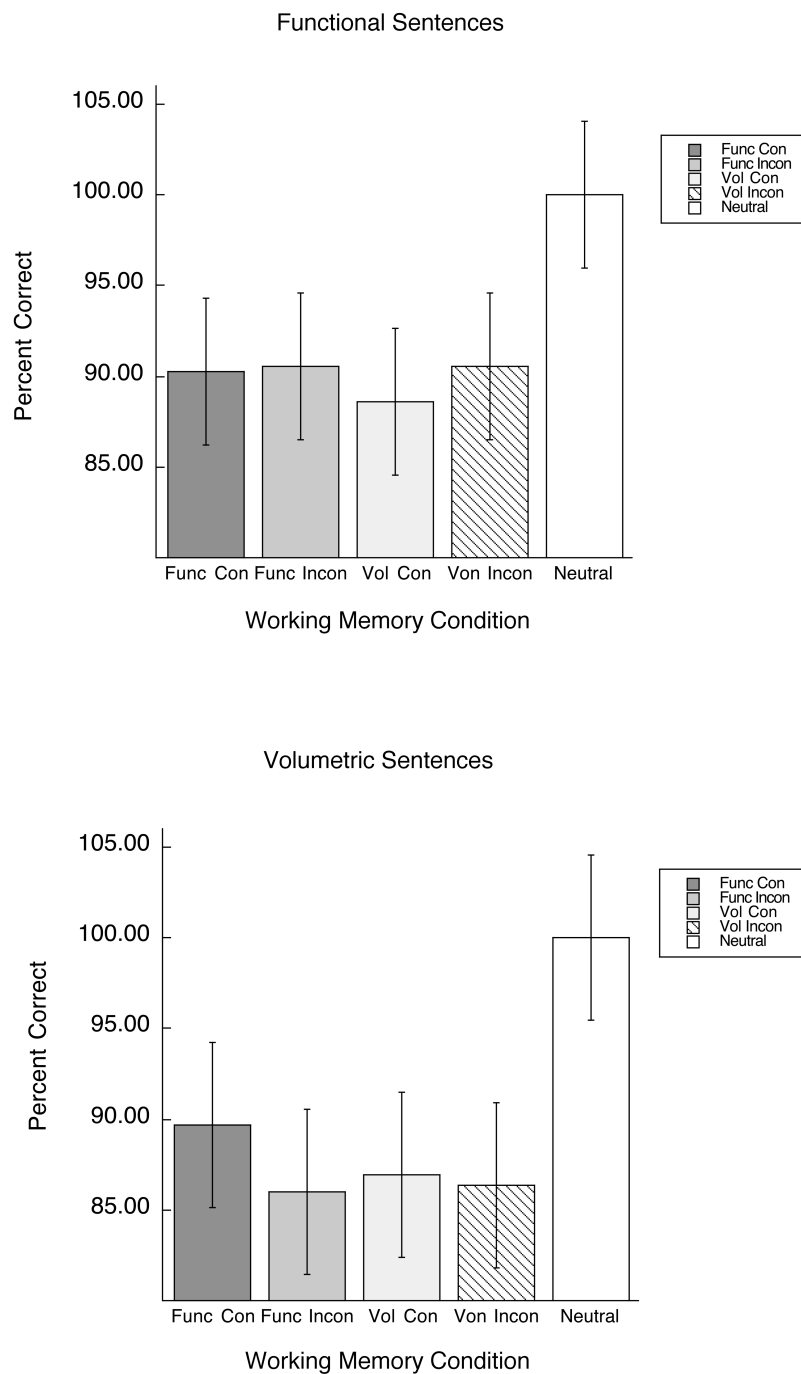


Figure 15. The mean percent of correct responses to comprehension questions associated with each working memory condition as a function of sentence type (functional and volumetric).

These data are for DG2 sentences.

Given that null results were obtained for each of the analyses not all of the graphs are described in this chapter. The rest of the analyses yield similar findings with no robust differences found between the five working memory conditions. Plots for these dependent measures are displayed in Appendix A in Figure 24. through to Figure 29.

2.3 Discussion

The lack of significant difference between working memory conditions for all of the dependent measures has several possible causes. First, subjects may not have been reading normally as they would outside of the experiment. Second subjects may have been encoding the hand actions verbally rather than visually, and third, keeping hand actions in working memory may not have had an impact on the processing of the sentences.

The high probability of skipping the word, “the” was unsurprising given that it is well established that high frequency words have higher rates of skipping than low frequency words (Blythe, Liversedge, Joseph, White, & Rayner, 2009; Liversedge et al., 2004; Rayner, Liversedge, & White, 2006; Rayner, Liversedge, White, & Vergilino-Perez, 2003; Choi & Gordon, 2013). Skipping rates can also be influenced by the predictability of the word being presented (Fitzsimmons & Drieghe, 2013). Brysbaert, Drieghe, and Vitu (2005) found that word skipping is highly mediated by the length of the word being presented. They plotted skipping frequencies against word lengths and found skipping rates of approximately 50% for small words (under 5 characters) and 25% for words longer words (word which are 5-9 characters long). The rates found in this experiment are consistent with those of Brysbaert, Drieghe, and Vitu (2005). For example, the word “the” had a skipping probability of 60% whereas the object noun and verb, which are longer words, displayed word skipping probabilities of approximately 30%. Given that the skipping rates found in this experiment are similar to rates reported for more

typical reading situations, they provide evidence against the possibility that subjects were not reading the sentences normally.

To further investigate whether subjects were reading normally, a list of words used in the following interest areas was compiled: first word after the object noun, second word after the object noun, third word after the object noun (DG2 sentences only), and last word (DG1 sentences only). Using the word frequency distributions provided by the English Lexicon Project the word frequency for each of the words was obtained and a correlation was computed between the natural logarithm of word frequency and gaze duration (Balota et al., 2007). It was hypothesized that high frequency words would receive shorter gaze durations as they are frequently used in the English language. This relationship is due to the assumption that a reader fixates on a word while it is being processed and continues to fixate on that word until processing is complete. Words that are low frequency take a longer time to process because they are less frequently called upon unlike high frequency words. Just and Carpenter (1980) produced findings consistent with this claim in which gaze duration was plotted against the natural log frequency of a word. The slope of the function was 53ms, or in other words, the gaze duration increased by 53ms for each unit increase of natural log frequency of a word. Consistent with the hypothesis a strong correlation was found between the gaze duration for a word and the natural log of its frequency [$r(1,59) = -.45, p < .001$]. The slope found in this study was 11ms, which is weaker than the slope found in that of Just and Carpenter (1980), but this is most likely due to a smaller range of frequency among the items used. This indicates that subject's were reading the sentences normally.

Subjects encoding the hand actions verbally could also have caused null results. Upon completion of the experiment many subjects mentioned that they had used the strategy of naming

the hand actions as a way to remember them. It is therefore possible that subjects were encoding the hand actions verbally into working memory rather than forming an action representation, which could be responsible for the null effects obtained in Experiment 1. Other possibilities are that since there were a limited number of hand images used subjects may have begun to encode the hand actions into long-term memory or perhaps the working memory load placed few demands on working memory. These suggestions are supported by the lack of significant difference found between having no working memory load and the other four types of working memory load on any of the dependent measures used. However, the significant difference found in gaze duration for the restricted hand classes suggests these proposals are not entirely correct. In an attempt to reduce the tendency to rely on verbal encoding, a second experiment was conducted which required subjects to remember both the hand action visually displayed as well as to mentally construct and remember the hand action required by the action described in the sentence. It was hypothesized that this requirement would force subjects to make a meaningful connection between the hand action and the sentences as on 20% of trials the two hand gestures would match.

3. Experiment 2

The objective of Experiment 2 was to determine whether and how different hand actions held in working memory might modulate sentence processing. Experiment 2 was a modified version of Experiment 1, and attempted to force subjects to make a meaningful connection between the hand action held in memory and the sentences being read. Experiment 2 used the same stimuli and task as Experiment 1 except for two small differences. In Experiment 2 only DG2 sentences were used as no difference was found between the two sentence structures. In addition, subjects were asked to pantomime the hand gesture required for the action depicted in the sentence instead of answering a yes or no question. Requiring subjects to hold both the presented hand action and the hand posture being used in the sentence in working memory was intended to encourage subjects to encode the hand images being displayed as hand actions rather than simply holding them in memory as visual images. It was expected that given these tasks subjects would encode the presented images as hand actions and that a difference would be found in sentence processing as a function of the type of working memory load. In Experiment 2 only DG2 sentences were used. DG2 sentences have been shown to evoke both functional and volumetric representations when the object noun is mentioned since the distal goal of the action has not yet been disclosed (Masson, Bub, & Lavelle, 2013). However, in DG1 sentences where the distal goal of the sentence is mentioned prior to the object noun, functional interpretation takes over and may possibly block volumetric representations from being evoked. Thus using DG2 sentences would allow for the investigation of whether functional or volumetric action representations modulate language processing.

3.1 Method

3.1.1. Subjects

Thirty students at the University of Victoria were tested. All subjects were native English speakers and received extra credit in an undergraduate psychology course for their participation.

3.1.2 Materials

The materials used in Experiment 2 were identical to those used in Experiment 1 except for a few alterations. First, only DG2 sentence were used in Experiment 2. Second, instead of comprehension questions about the sentences, subjects were asked to pantomime the hand action described in the sentence on a random 25% of trials. On another 25% of trials, subjects were asked to pantomime the hand action shown before the trial.

3.1.3 Procedure

The procedure for Experiment 2 was similar to Experiment 1 except for one change to the instructions given to the subjects. Subjects were asked to hold a hand action in working memory while reading a sentence and then to respond to any prompts that appeared after the sentence. Prompts could ask for a subject to report the displayed hand action or the sentence action. Both of these responses were marked by the experimenter as correct, incorrect, or spoiled and were then followed by the next trial.

3.1.4 Data Analysis

The mean reading time for each sentence, hand action pantomime accuracy, and sentence gesture pantomime accuracy were recorded. Only DG2 sentences were used which were shorter in length than DG1 sentences, thus reading time was much shorter overall for Experiment 2. For mean reading time any sentence with a reading time of less than 100ms or over 6300ms were

excluded from the analysis. The upper boundary for excluded reading time data was lower than that of Experiment 1 because of the shorter overall reading times. These cut-offs resulted in 0.486% of the data being excluded.

The interest areas used in Experiment 2 were identical to those used for the DG1 sentences in Experiment 1. Again gaze duration, first fixation, probability of interest area skipping, probability of return to an interest area, saccade length, and pupil size were analyzed across the functional and volumetric sentences for the seven interest areas.

3.2 Results

As with Experiment 1, Experiment 2 also yielded high accuracy in responses to both types of prompts, with a 91.29% mean accuracy for pantomiming the displayed hand action and a 90.98% mean accuracy for pantomiming the hand action described in the sentence. These results indicate that subjects were attending to the hand actions and sentences. Eye-fixation data from trials where a response error occurred were excluded from our analysis.

Similar to Experiment 1, null results were obtained for each of the analyses. To provide examples of the results found in Experiment 2 gaze duration is presented in Figure 16, the probability of word skipping is displayed in Figure 17, and the first fixation duration is displayed in Figure 18. Plots of the remaining dependent measures can be found in Appendix B in Figure 30. through to Figure 32. As in Experiment 1 analyses were carried out on the restricted hand classes in functional and volumetric sentences for gaze duration and first fixation. The findings from these analyses in Experiment 1 were not replicated and the results can be viewed in Figure 19 for gaze duration and Figure 20 for first fixation. To determine the ability to detect the presence of an effect, statistical power was computed using the program G*Power with a Cohen's d of 0.06 as the assumed effect size (Cohen, 1988; Faul, Erdfelder, Lang, & Buchner,

2007), based on the effect observed in Experiment 1. Given that the power found for congruent and incongruent hand postures when aggregating across functional and volumetric sentences was 0.09 no strong conclusions can be drawn about the nonsignificant results found for the restricted hand classes in Experiment 2. Reading time is displayed in Figure 21 and sentence pantomime and display gesture pantomime accuracy can be viewed in Figure's 22 and 23.

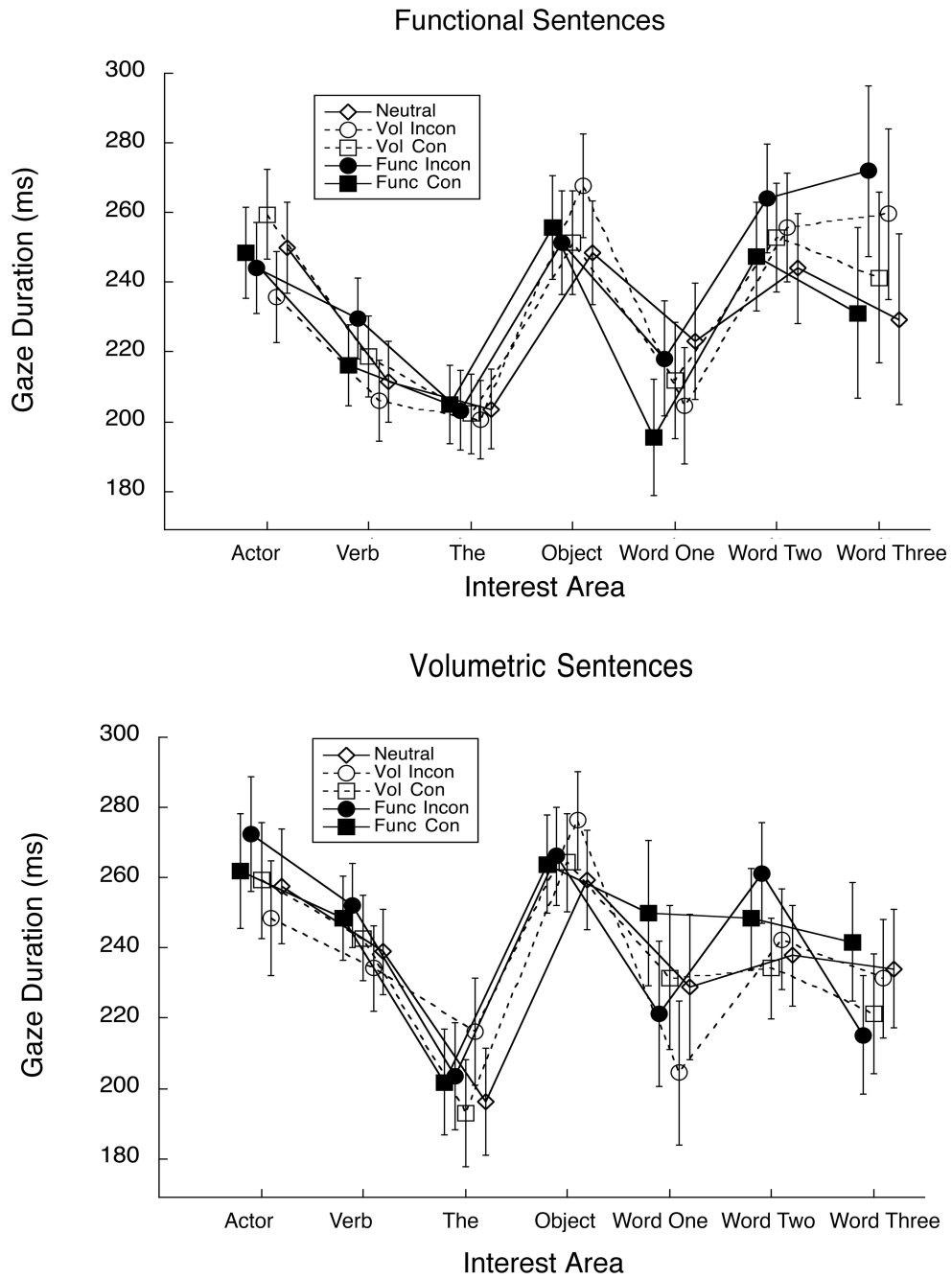


Figure 16. Gaze duration associated with each working memory condition as a function of sentence type (functional and volumetric) and interest area. Data points within each segment are staggered for visual clarity.

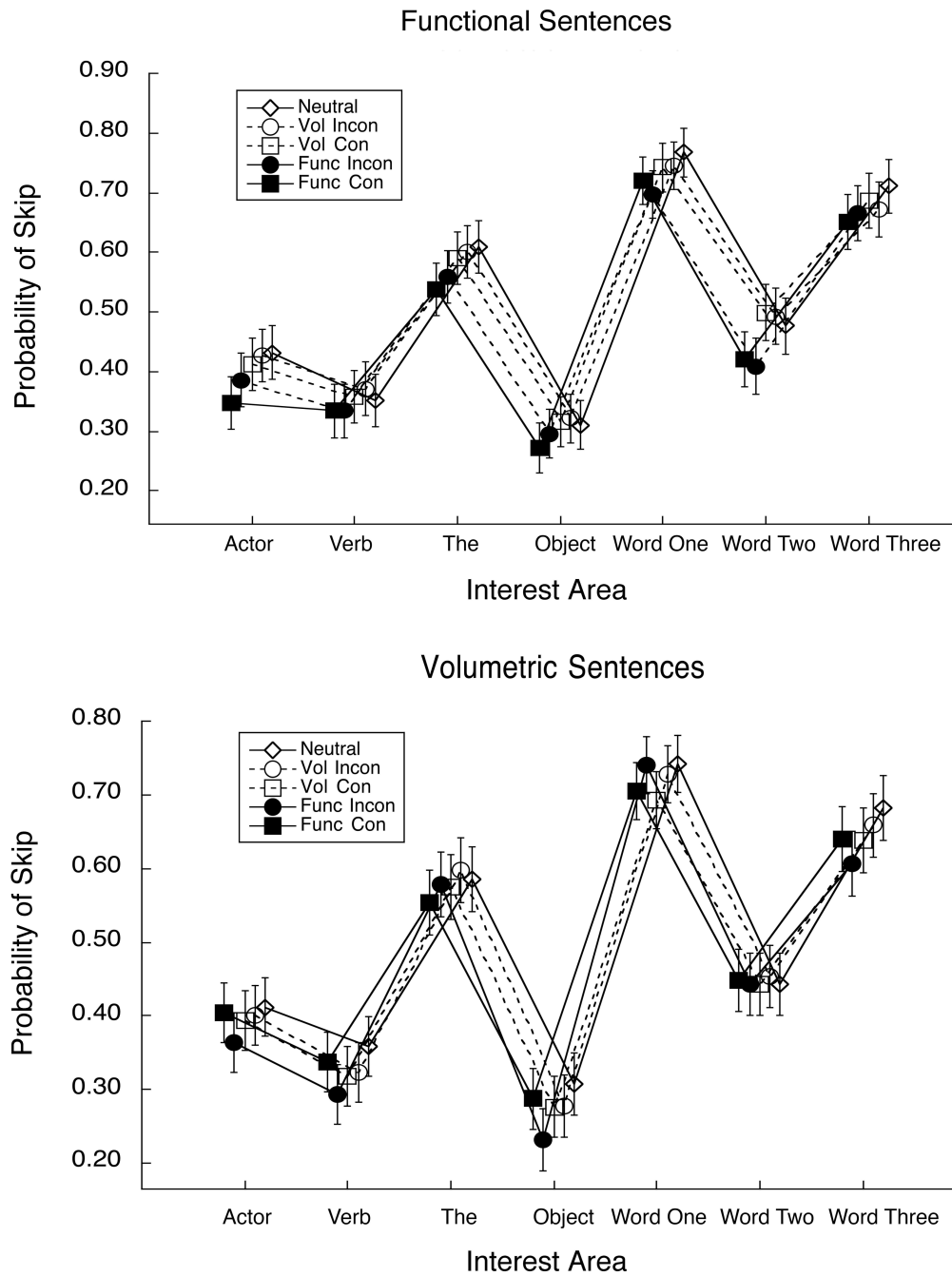


Figure 17. The probability of skipping a word associated with each working memory condition as a function of sentence type (functional and volumetric) and interest area. Data points within each segment are staggered for visual clarity.

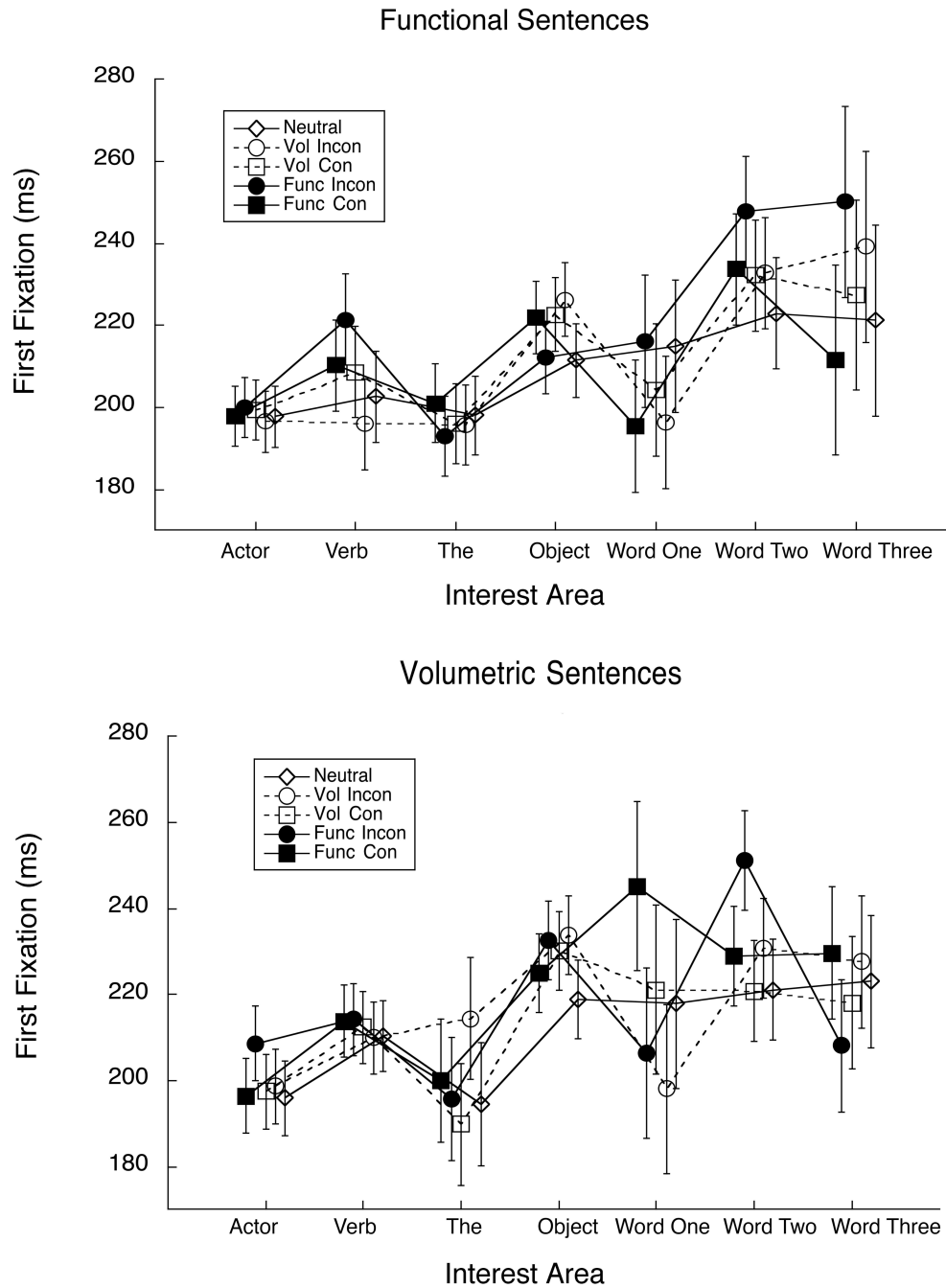


Figure 18. The first fixation duration on a word associated with each working memory condition as a function of sentence type (functional and volumetric) and interest area. Data points within each segment are staggered for visual clarity.

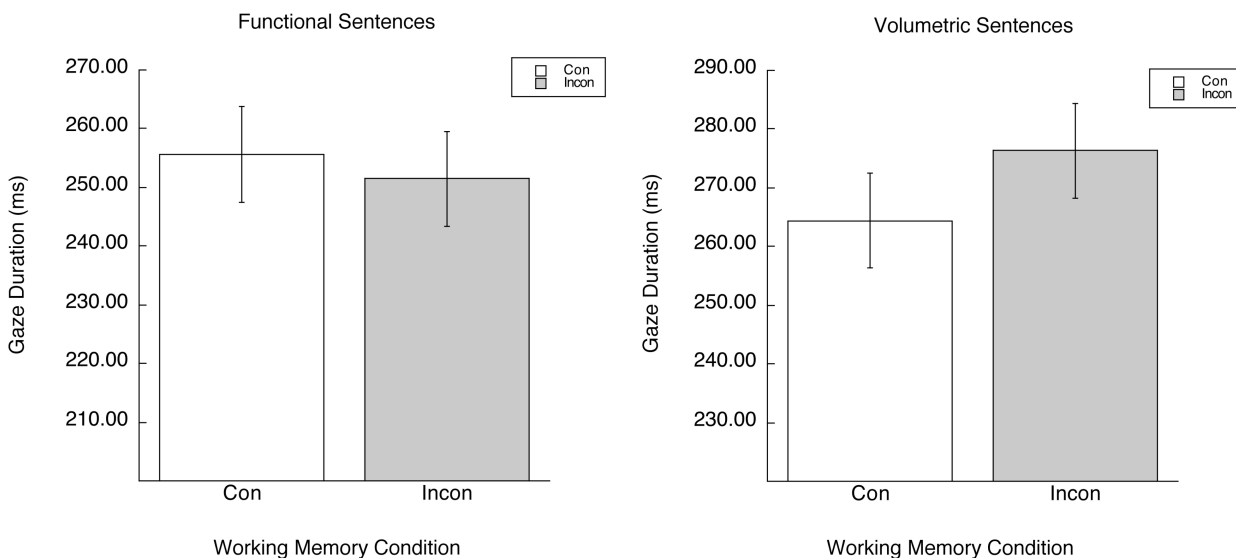


Figure 19. Gaze duration associated with each context relevant working memory condition for functional and volumetric sentences.

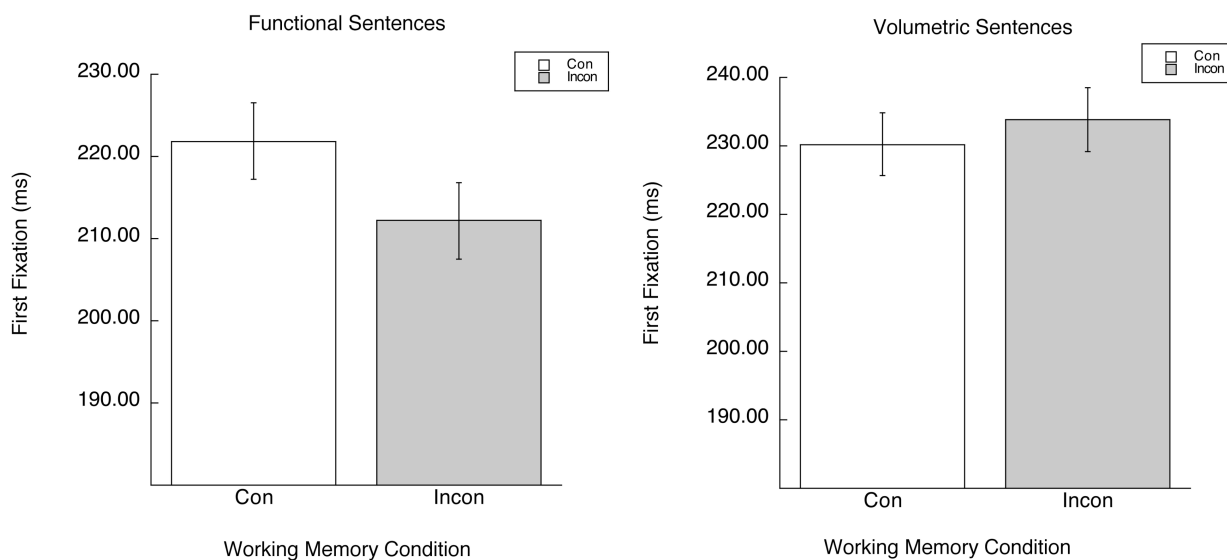


Figure 20. First fixation duration associated with each context relevant working memory condition for functional and volumetric sentences.

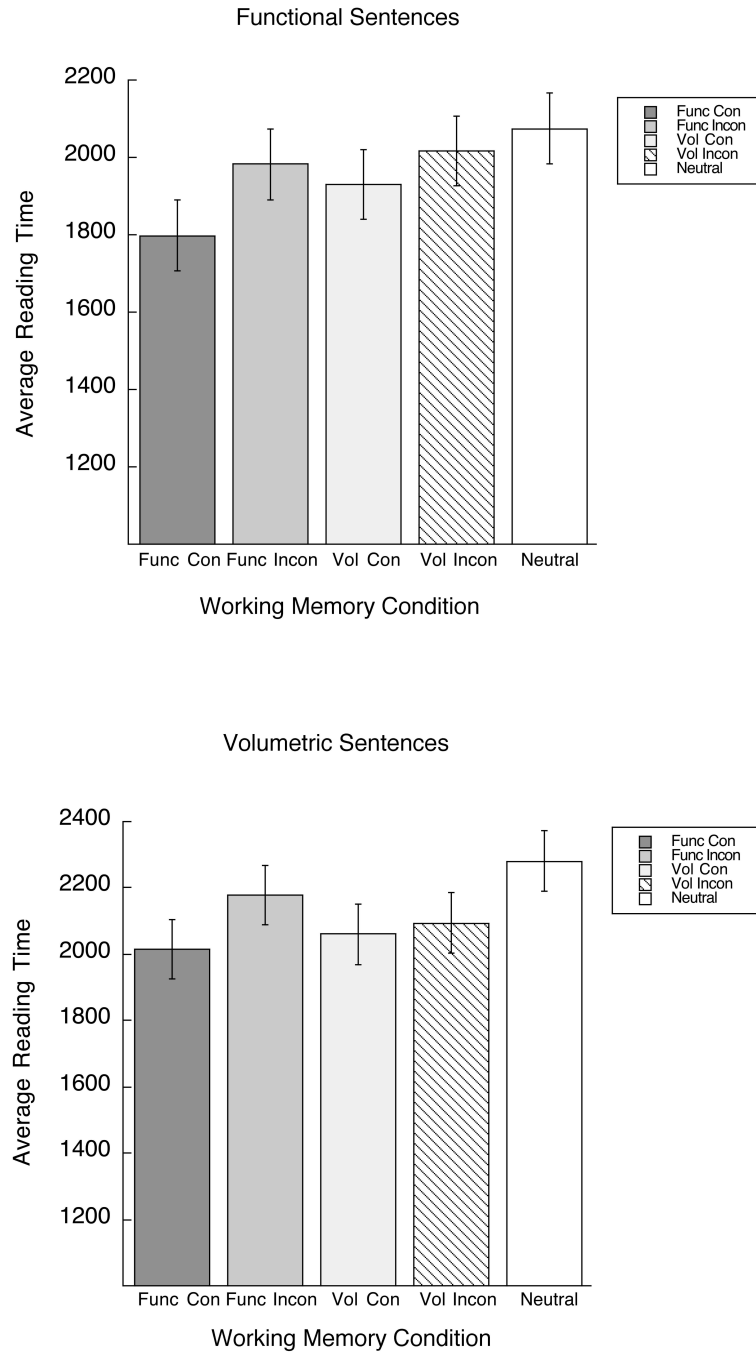


Figure 21. The mean reading time associated with each working memory condition as a function of sentence type (functional and volumetric).

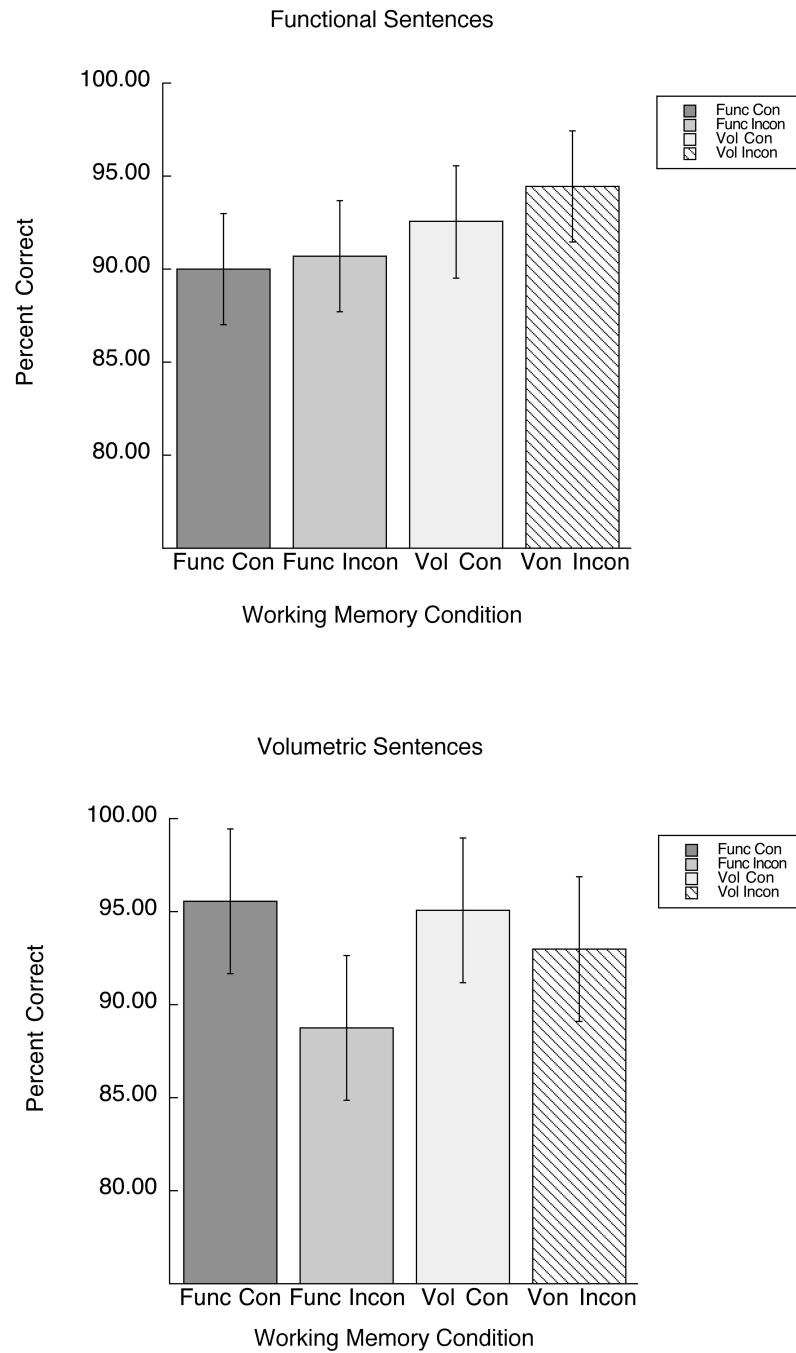


Figure 22. The mean percent of correct responses to hand action pantomime prompts associated with each working memory condition as a function of sentence type (functional and volumetric).

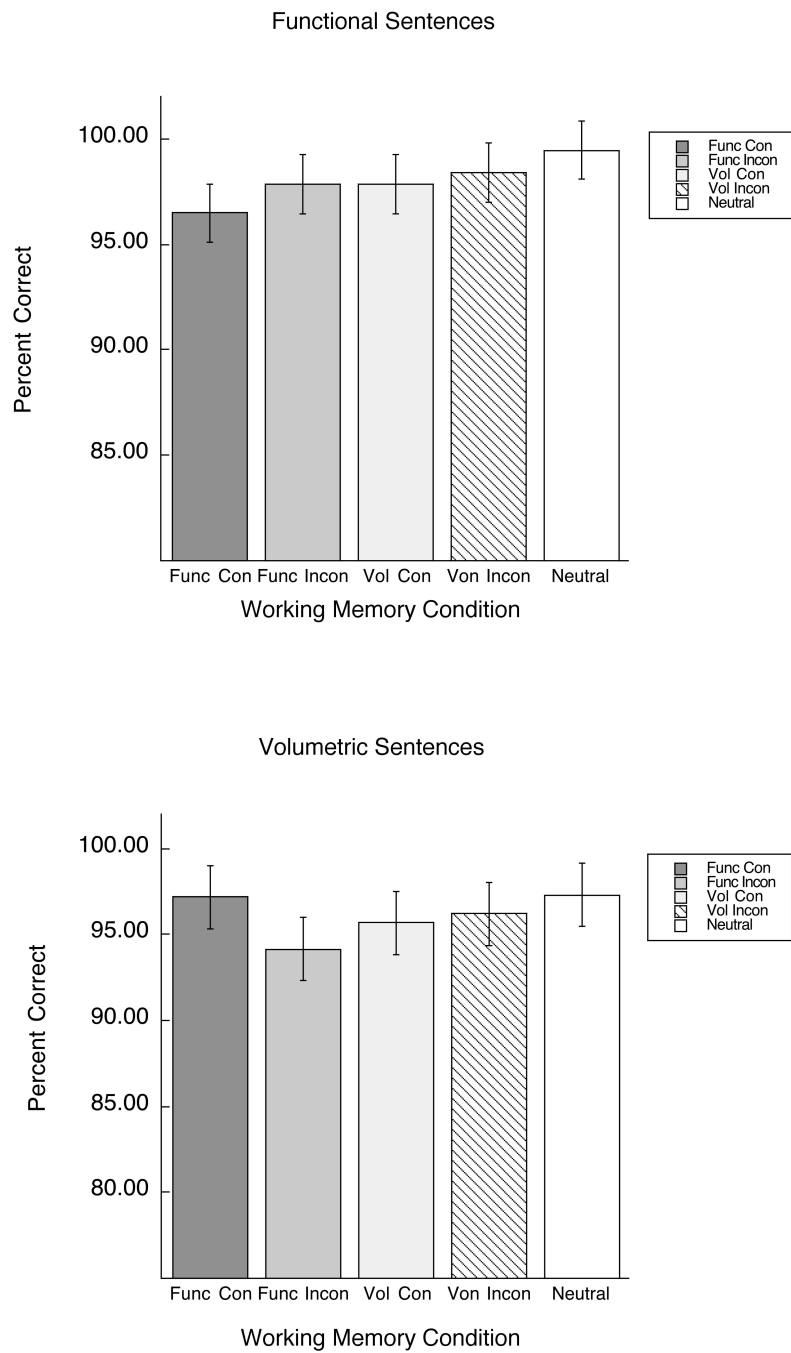


Figure 23. The mean percent of correct responses to sentence gesture pantomime prompts associated with each working memory condition as a function of sentence type (functional and volumetric).

3.3 Discussion

The results from Experiment 2 provide several possible conclusions. First subjects may still not have been encoding the hand actions into working memory as expected.. Subjects may have been using verbal encoding to hold the hand actions in memory or may have encoded the hand postures into long-term memory. Second, it is possible that the working memory load was not adequate to cause action representations of the hand action to form. Additional research using methods that can ensure the hand images are being encoded as hand action responses is required to conclude whether this hypothesis is true. For example, requiring subjects to pantomime the motion of the hand action during varying times while reading the sentences would encourage subjects to create a action representation of the movement that follows from the hand action instead of encoding the hand action visually. Finally, it is possible that keeping a hand action in working memory does not impact on the processing of a sentence, in which case no additional manipulations would cause a modulation of sentence processing.

4. General Discussion

Two theories surrounding the role of action representations were considered. First, action representations play a functional role in the comprehension process and are required for comprehension to occur (Barsalou, 2008; 2009). Alternatively, action representations may have no functional role in language comprehension and may instead be evoked as by products of the comprehension process (Mahon, & Caramazza, 2008).

The purpose of this research was to determine the role of action representations in language processing. Use of eye tracking methodology allowed for a detailed analysis of eye movements and whether sentence processing was being modulated depending on the type of hand action held in working memory. Although previous studies have used phrases to determine whether action representations will affect motor planning and action, (Glenberg, and Kaschak, 2002; Markman, & Brendl, 2005) Experiment 1 provided a more direct study of the role of action representations by requiring subjects to read a sentence while holding a hand action in working memory. The results showed no significant difference between any of the hand action types being held in working memory. Three of the possible conclusions are, first, that the sentences used in the experiment may have been too highly structured causing subjects to read them in an irregular fashion. Although this is a possibility, the probability of skipping rates and negative correlation between gaze duration and natural logarithm of a words frequency provide evidence against this idea. The probability of skipping words is similar to what would be expected for normal reading with higher skipping rates occurring for high frequency words. In addition, the correlation between the gaze duration and the natural log frequency of a word showed that low frequency words receive longer gaze durations than high frequency words

which is also consistent with normal reading. Second, subjects may not have encoded the hand images displayed to them as hand actions and finally, holding a hand action in working memory may not affect sentence processing.

Experiment 2 attempted to encourage subjects to encode the hand images as action representations by prompting for pantomime responses for both the sentence action and display action. The results of Experiment 2 were identical to Experiment 1 in that no significant results were found for processing the sentences between any of the five hand action conditions.

The results of Experiment 1 and 2 may appear at first glance to support the position that action representations have no functional role in language comprehension but alternative explanations are also supported by the data. First, the gaze duration and first fixation duration analysis for the restricted hand classes indicate that action representations may be modulating sentence processing. Second, the sentences used in both Experiment 1 and Experiment 2 were highly structured which could have caused subjects to process the sentences in a fashion incongruent with how they would under normal circumstances. To investigate whether this was the case a correlation was computed between the natural logarithm of word frequency for words found in the interest areas, first word, second word, and third word following the object noun, (DG2 sentence) as well as the last word of the opening phrase (DG1 sentences) and gaze duration. Finally, subjects may still not have been encoding the hand actions being displayed as action representations. This could be due to the pantomimes required of the subjects or the working memory load being encoded as a verbal representation rather than an action representation or subjects encoding the hand postures into long memory therefore leaving working memory without a cognitive load. To conclude whether this was the cause of the null results obtained in the current experiments future research is required.

It is suggested that future research attempt to encourage subjects to hold the hand actions as prepared action states rather than action representations. To achieve this, subjects would be required to commit an action immediately and would be cued to do so at various points throughout sentences. By requiring this, subjects must hold the hand action as a prepared state that can be released readily upon cue. This method might eliminate the conjecture of whether subjects are encoding hand actions as action representations and the need for subjects to then translate them into an action when cued to respond. Conducting this type of study should allow more certainty about how the hand postures are being held in memory and will therefore allow for conclusions to be drawn about whether working memory affects sentence processing.

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6. Appendix A: Experiment One Figures

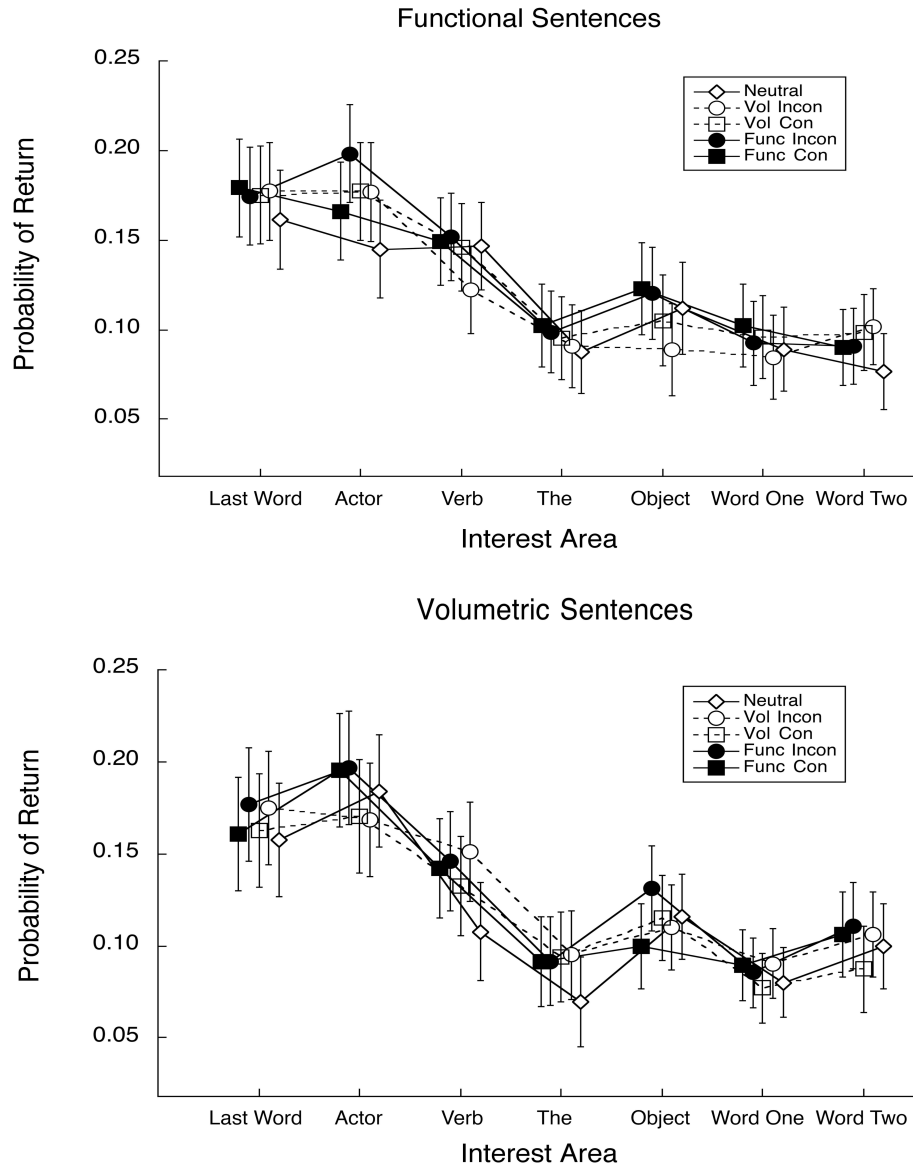


Figure 24. The probability of returning to a word associated with each working memory condition as a function of sentence type (functional and volumetric) and interest area. These data are for DG1 sentences. Data points within each segment are staggered for visual clarity.

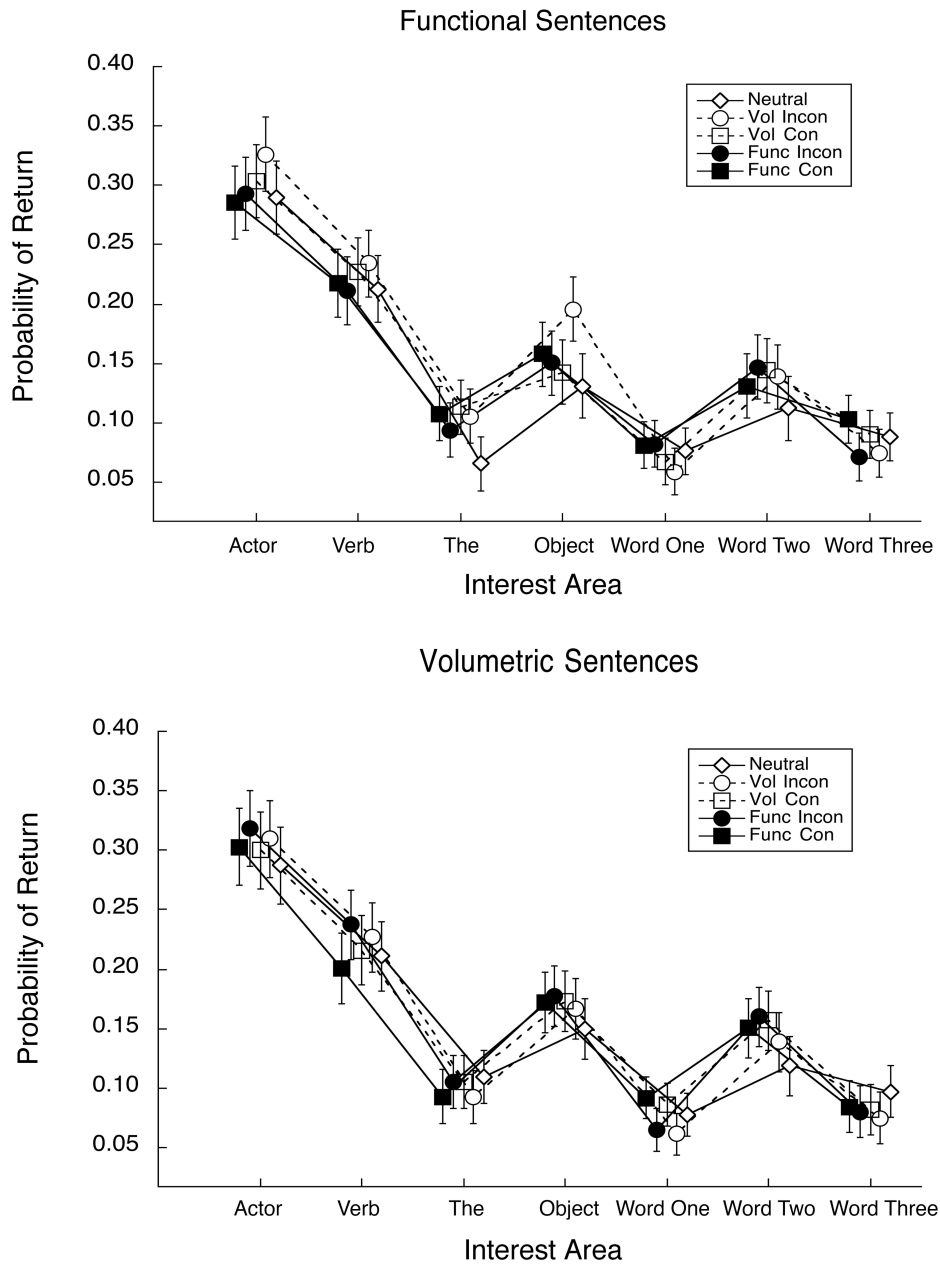


Figure 25. The probability of returning to a word associated with each working memory condition as a function of sentence type (functional and volumetric) and interest area. These data are for DG2 sentences. Data points within each segment are staggered for visual clarity.

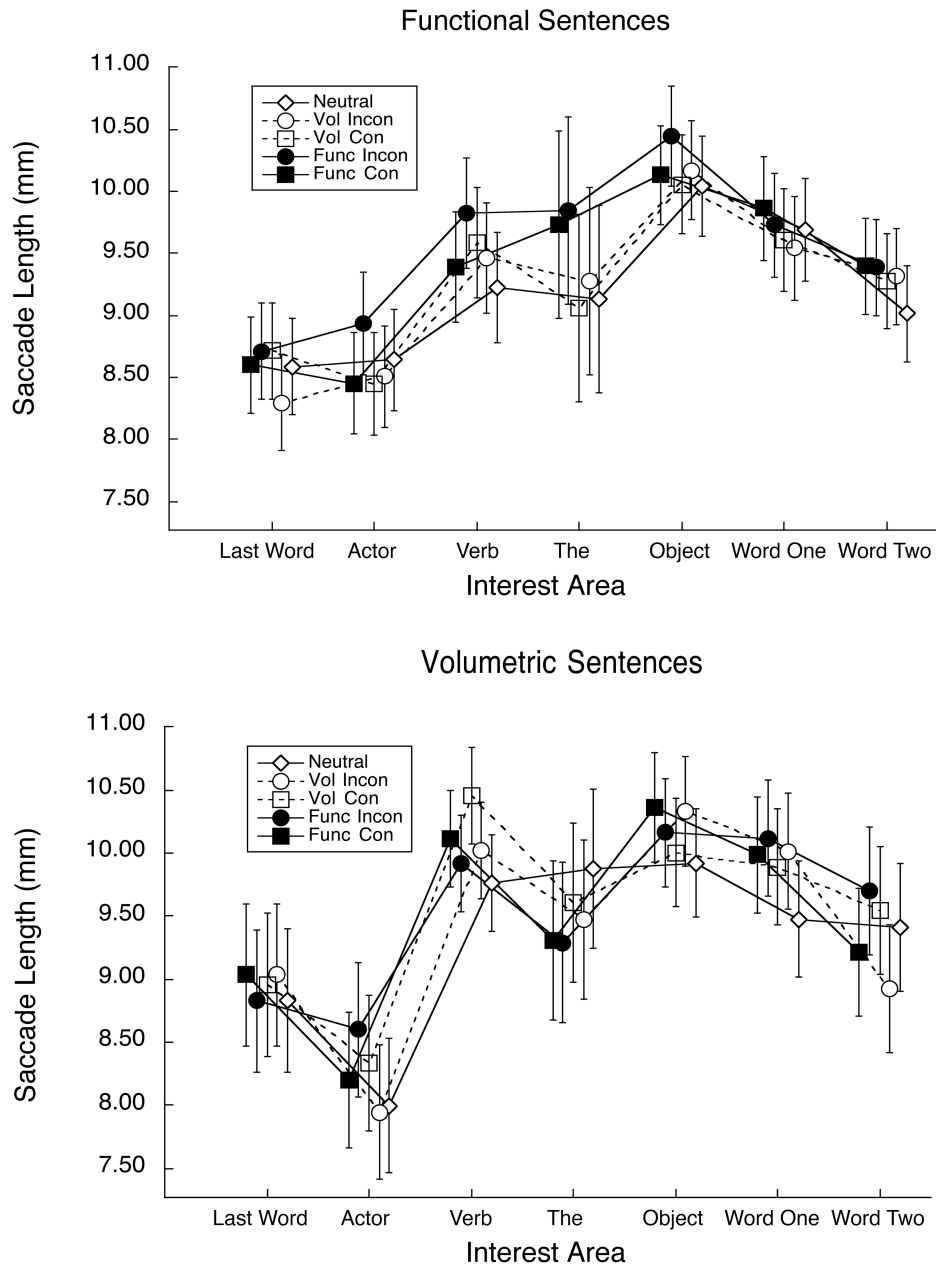


Figure 26. The saccade length away from a word associated with each working memory condition as a function of sentence type (functional and volumetric) and interest area. These data are for DG1 sentences. Data points within each segment are staggered for visual clarity.

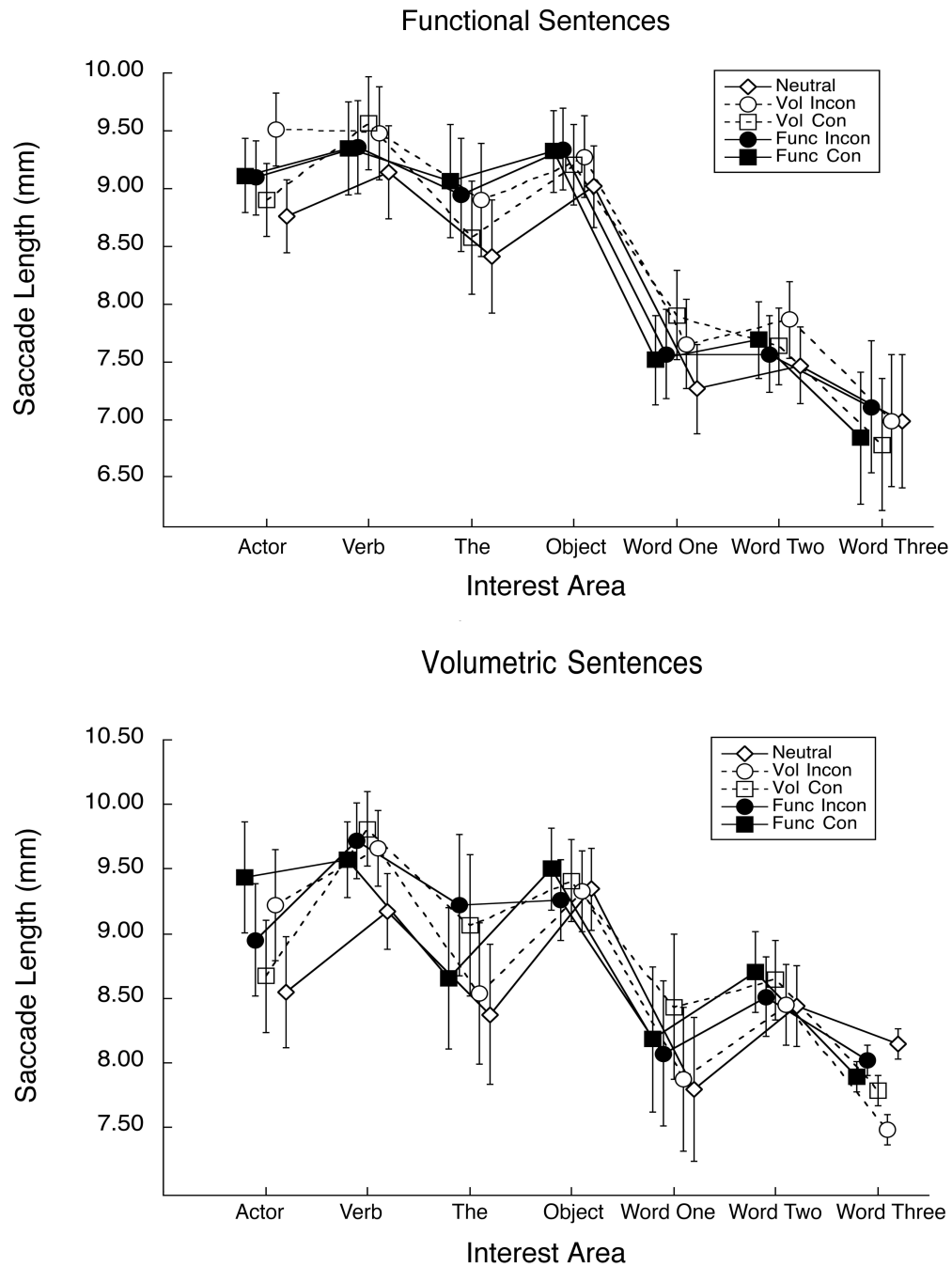


Figure 27. The saccade length away from a word associated with each working memory condition as a function of sentence type (functional and volumetric) and interest area. These data are for DG2 sentences. Data points within each segment are staggered for visual clarity.

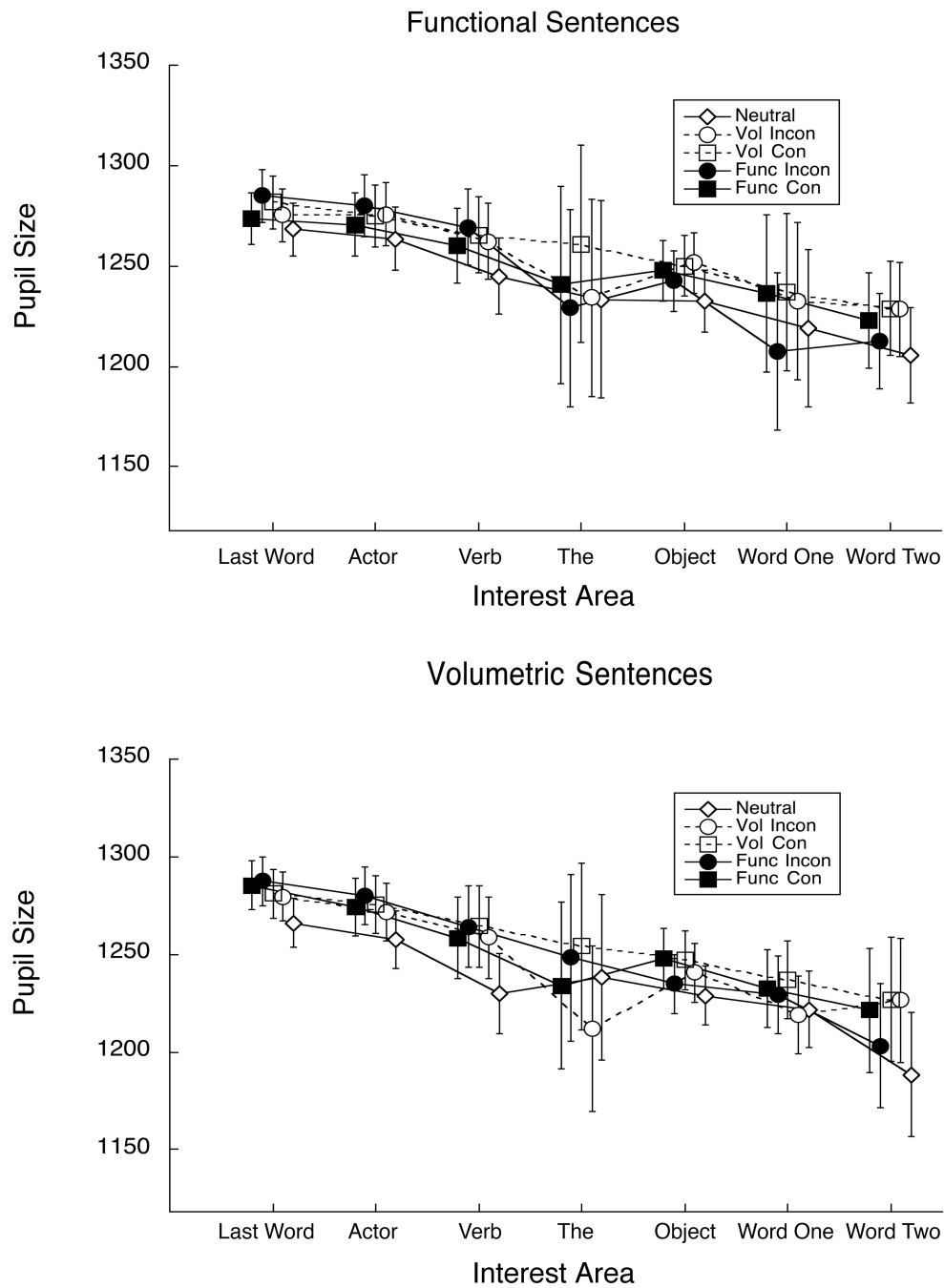


Figure 28. The average pupil size diameter while viewing a word associated with each working memory condition as a function of sentence type (functional and volumetric) and interest area. These data are for DG1 sentences. Data points within each segment are staggered for visual clarity.

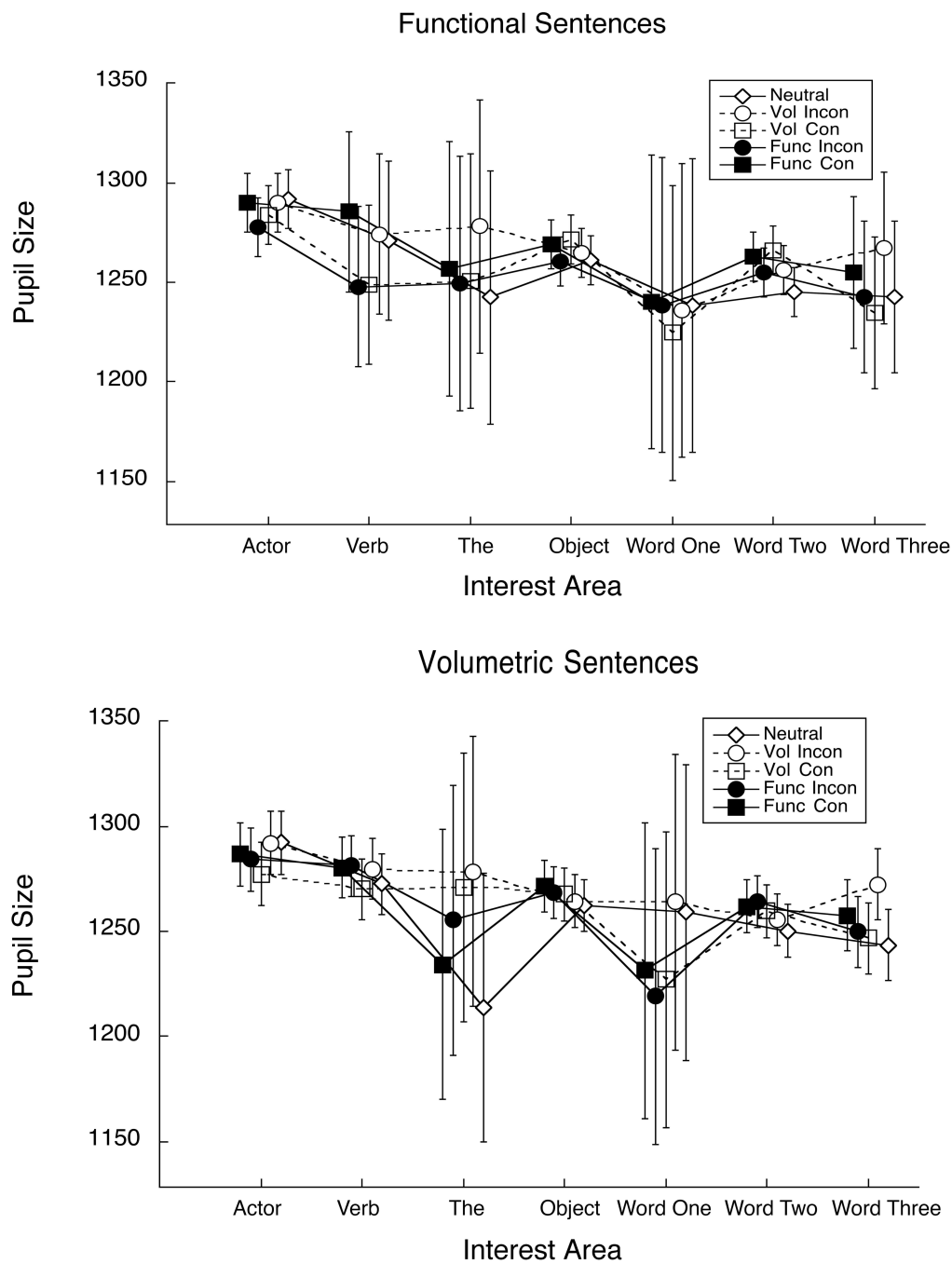


Figure 29. The average pupil size diameter while viewing a word associated with each working memory condition as a function of sentence type (functional and volumetric) and interest area. These data are for DG2 sentences. Data points within each segment are staggered for visual clarity.

7. Appendix B: Experiment Two Figures

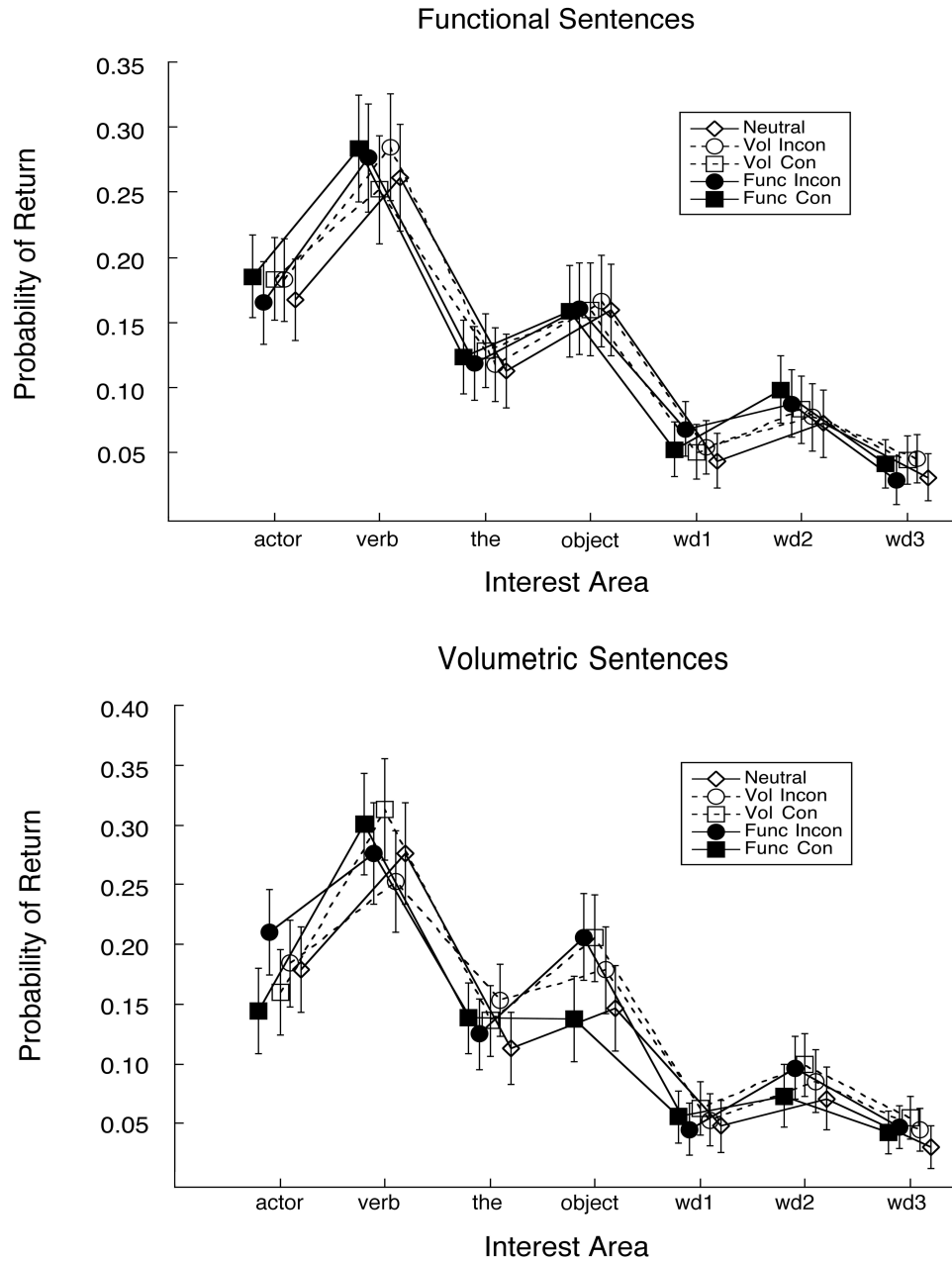


Figure 30. The probability of returning to a word associated with each working memory condition as a function of sentence type (functional and volumetric) and interest area. Data points within each segment are staggered for visual clarity.

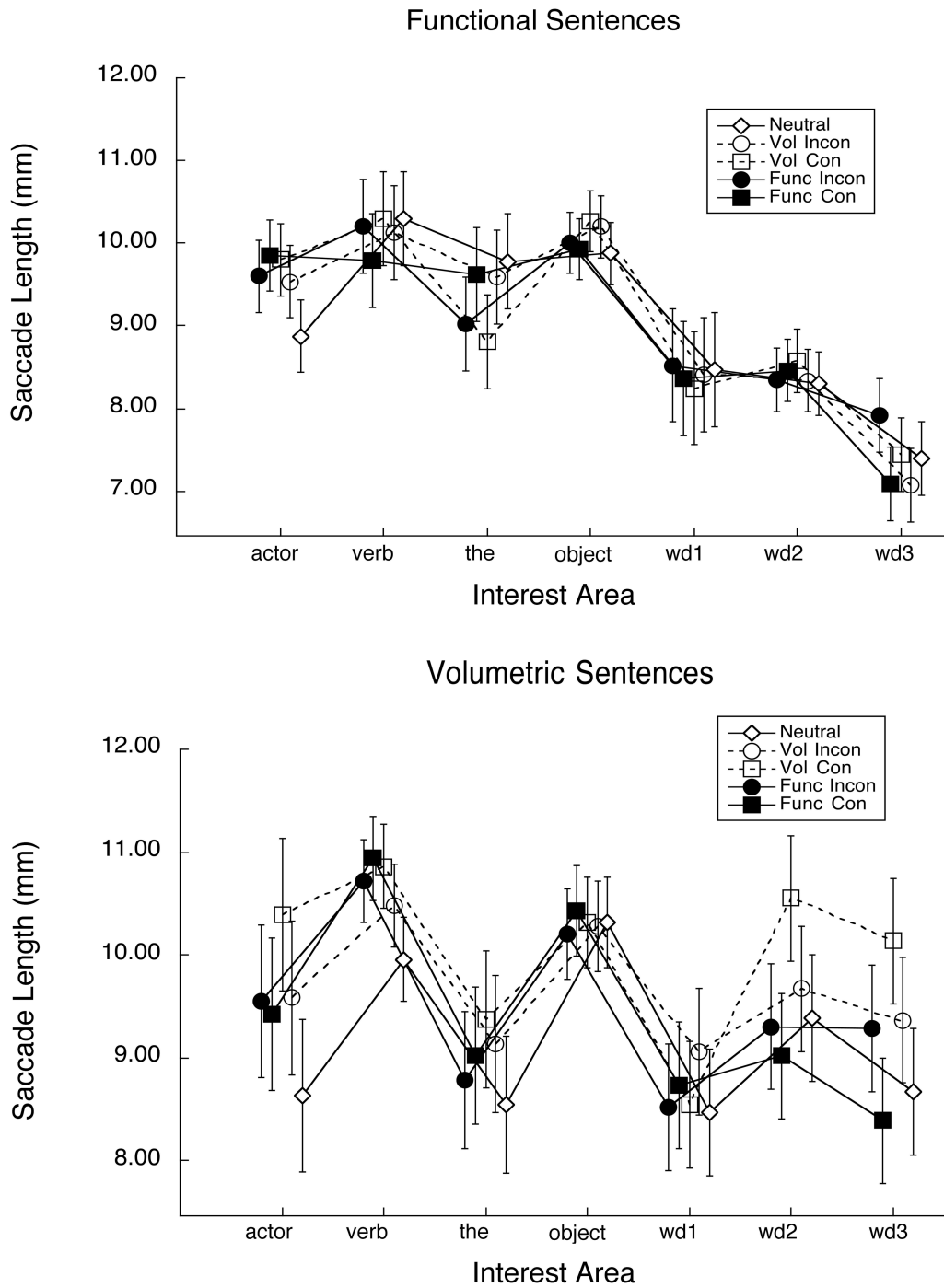


Figure 31. The saccade length away from a word associated with each working memory condition as a function of sentence type (functional and volumetric) and interest area. Data points within each segment are staggered for visual clarity.

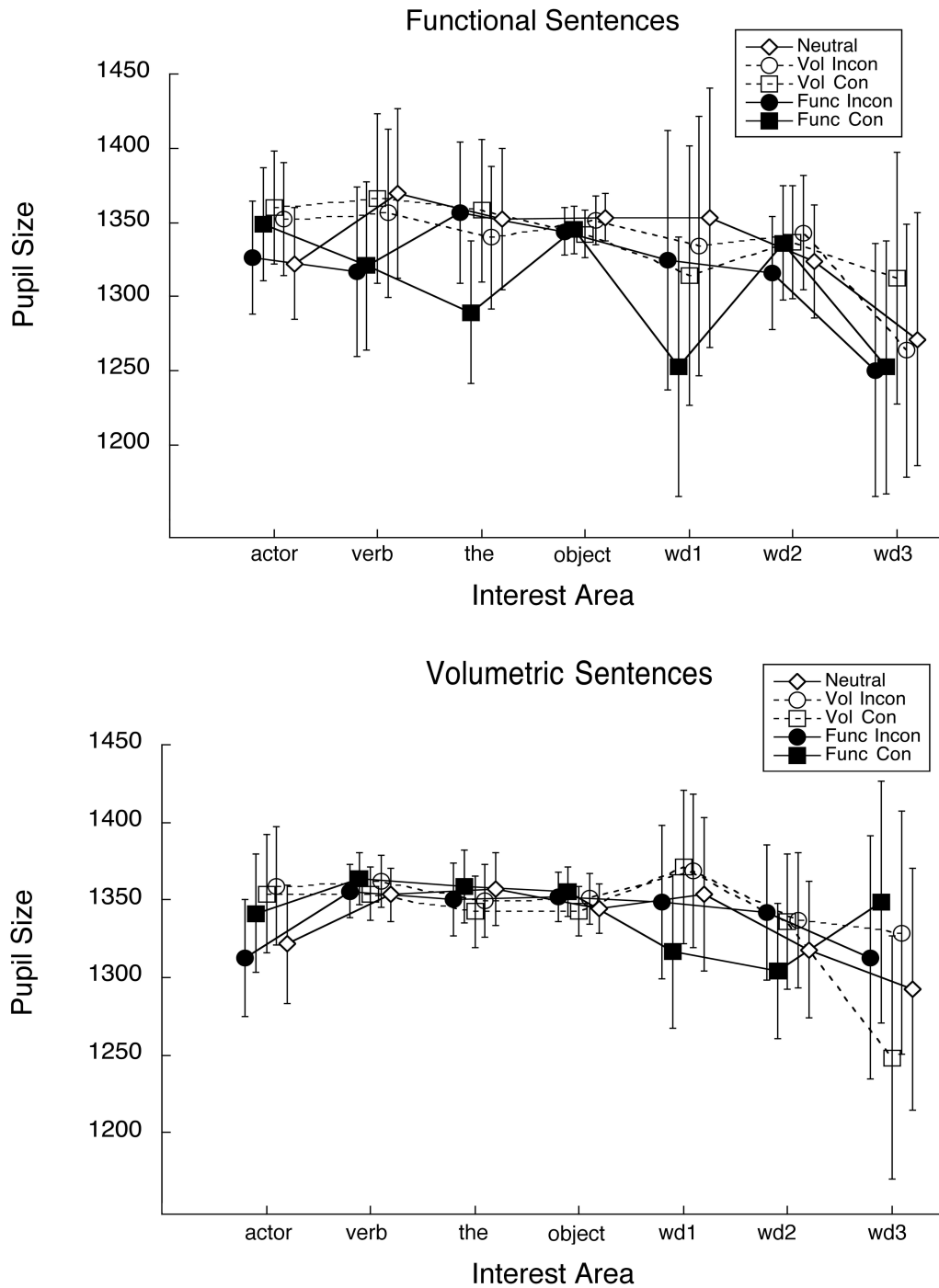


Figure 32. The average pupil size diameter while viewing a word associated with each working memory condition as a function of sentence type (functional and volumetric) and interest area. Data points within each segment are staggered for visual clarity.