EYE-TRACKING INVESTIGATIONS OF LEXICAL AMBIGUITY

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by

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The undersigned, appointed by the Dean of the Graduate School, have examined the dissertation entitled

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ABSTRACT

The purpose of this study was twofold: to investigate the time course of ambiguity resolution and to examine methodological issues associated with the visual world paradigm. In seven experiments, participants viewed visual stimuli while they listened to auditory stimuli containing an ambiguous word, and their visual fixations were monitored with an eye-tracking camera. Experiment 1 involved the presentation of four clip-art pictures within a passive viewing paradigm (no explicit instructions to fixate related pictures). Two of these pictures were semantically related to the ambiguous word; one was related to the dominant (most frequent) meaning of the word, and the other was related to a subordinate (less frequent) meaning. The auditory stimuli consisted of an unbiased question containing the ambiguous word, which was followed by a reply containing information that was biased toward one of the two meanings. Meaning activation was determined by comparing the probability of fixating each related target to the average probability of fixating an unrelated picture. Fixation probabilities revealed that the dominant meaning was activated more strongly and rapidly than the subordinate meaning. However, revision of the initial frequency-based interpretation occurred if the disambiguating reply was consistent with the subordinate meaning. The results also revealed effects of awareness and strategy use: participants who were aware of the presence of related targets and intentionally fixated them demonstrated greater fixation rates for related pictures and were more likely to activate the subordinate meaning prior to the reply. Experiments 2 through 7 involved modifications to the procedure and/or stimuli utilized in Experiment 1, exploring the effects of the type of visual stimulus (pictures or words), the type of instructions (passive or active), the number of related targets (two per trial or one per trial), and the placement of the disambiguating context (prior to the ambiguous word, subsequent to the ambiguous word, or delayed following the ambiguous word). The results revealed the following: 1) Fixation patterns differ between pictures and words, even when an active viewing task is utilized. 2) An active viewing task enhances activation of the dominant meaning and slows meaning revision. 3) There are competition effects when multiple related targets are presented, but presenting a single related target enhances activation for the meaning to which it is related. 4) The contextually-consistent meaning is typically selected soon after the disambiguating information occurs, but exhaustive access occurs when the prior biasing context is consistent with the subordinate meaning.

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EYE-TRACKING INVESTIGATIONS OF LEXICAL AMBIGUITY

Ambiguity is pervasive in language. Ambiguity can occur at multiple levels of language processing: at the discourse level (e.g., Bransford & Johnson, 1972), at the level of syntactic parsing (e.g., Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995), at the level of the individual word (e.g., Swinney, 1979), and at the level of phonology (e.g., Liberman, Cooper, Shankweiler, & Studdert-Kennedy, 1967). The current study focuses on ambiguity at the level of the individual word, which is known as lexical ambiguity.

Lexical ambiguity is not of interest because its occurrence is a novelty, but because its occurrence is frequent – many words have multiple meanings. George Miller (as cited in Tabossi & Sbisa, 2001) has pointed out that the polysemous nature of words is actually beneficial, reducing the number of words one must learn. However, polysemy also results in ambiguity, and the comprehender must resolve this ambiguity at some point. Lexical ambiguity is of interest not only as a basic issue in psycholinguistics, but also as a more applied issue: it has been demonstrated that less-skilled readers experience greater difficulty with lexical ambiguity than more-skilled readers (Gernsbacher, Varner, & Faust, 1990).

Semantic Priming

Studies of lexical ambiguity resolution (e.g., Simpson, 1981; Swinney, 1979) often focus on the absence or presence of semantic priming effects (Meyer & Schvaneveldt, 1971). In tasks such as lexical decision and speeded naming, reaction times are faster when a target word is preceded by a semantically-related prime (e.g., DOCTOR-NURSE) than when an unrelated prime is used (e.g., CHAIR-NURSE). A common interpretation of semantic priming effects is that processing of the prime results in semantic activation that spreads to related concepts, resulting in partial activation of the related target word prior to its presentation (Collins & Loftus, 1975). The partial activation is thought to facilitate processing of the target word when it is presented, resulting in more rapid reaction times. Thus, when a semantic priming effect occurs, one can argue that the meaning of the target word has been activated in semantic memory. In studies of lexical ambiguity, the presence or absence of semantic priming effects has been used to investigate the activation and selection of specific related meanings.

Effects of Biasing Context and Meaning Frequency

Much of the research on ambiguity resolution has focused on the potential influences of biasing semantic or pragmatic information on initial lexical access (e.g., Onifer & Swinney, 1981; Simpson, 1981; Swinney, 1979; Tabossi, 1988). These studies have been concerned with the following question: is initial lexical access impervious to non-lexical sources of information (e.g., the broader semantic context)? Three primary models have been proposed, as well as hybrid models. According to the *exhaustive access model* (Swinney), multiple meanings of an ambiguous word are initially activated, despite the presence of biasing semantic or pragmatic information that occurs prior to the ambiguous word (e.g., in a sentence like *"The office walls were so thin that they could hear the ring of their neighbor's phone whenever a call came in."*; Onifer & Swinney). Like the exhaustive access model, the *ordered access model* (Hogaboam & Perfetti, 1975) also suggests that prior biasing context does not have an effect on initial meaning activation. The model suggests that the dominant (most frequent) meaning is initially activated, and the subordinate (less frequent) meaning is only activated if the dominant meaning is not consistent with the context. In contrast to the exhaustive and ordered access models, which hold that initial lexical processing is context independent, the *selective access model* (Swinney & Hakes, 1976) suggests that initial lexical access can be influenced by prior biasing information, with only the contextually-consistent meaning being initially activated. *Hybrid models* typically combine features of ordered access and selective access models (e.g., Duffy, Morris, & Rayner, 1988). For example, the *reordered access model* developed by Duffy et al. suggests that contextual information that is biased towards the subordinate meaning can result in activation of the subordinate meaning that coincides with activation of the dominant meaning, but subordinate-biased context does not result in selective access of the subordinate meaning.

Ambiguity Resolution in a Neutral Context

Some studies have examined the time course of ambiguity resolution in a completely neutral context. For example, Simpson and Burgess (1985) found that priming effects occurred when a target related to the dominant meaning of an ambiguous word was presented (e.g., BANK-MONEY), regardless of the specific stimulus onset asynchrony (SOA) that was used (the range was 16 ms to 750 ms). In contrast, priming effects for subordinate-related targets (e.g., BANK-RIVER) did not occur at the earliest or latest SOA's, but did occur at intermediate SOA's (peaking at 300 ms). These findings have several implications regarding ambiguity resolution in a neutral context: multiple meanings are typically activated; the dominant meaning is activated more quickly and remains active over time; activation of the subordinate meaning dissipates over time. The dominant meaning is ultimately selected, but it is unclear if selection is driven by attentional processes (Neely, 1977), such as attention to the dominant meaning or suppression of the subordinate meaning, or if selection occurs because activation of the subordinate meaning simply decays over time.

The Roles of Attention and Working Memory

According to Neely's *two-process model* of word recognition (1977), automatic spreading activation occurs quickly, followed by slower attention-driven processing; facilitation at longer SOA's indicates that attention has been directed to the primed semantic relationship, whereas inhibition indicates that attention has been directed to other semantic relationships. In an additional experiment, Simpson and Burgess (1985) demonstrated that selection of the dominant meaning (at the 750 ms SOA) was due to attentional processes: compared to a neutral prime (a series of dashes), dominant-related targets preceded by ambiguous primes were facilitated (reaction time was faster than baseline), whereas subordinate-related targets were inhibited (reaction time was slower than baseline). However, Simpson and Burgess found the same pattern of results when they manipulated the probability that a subordinate- or dominant-related target would occur, even when they informed participants that subordinate-related targets were more likely to occur. Simpson and Burgess argued that meaning selection involves attention to the dominant meaning and inhibition of the subordinate meaning, but despite the involvement of attention, selection processes are difficult to control.

Other work has investigated the contributions of attention-demanding processes to ambiguity resolution. For example, Gernsbacher et al. (1990) focused on suppression of an irrelevant meaning, whereas Miyake, Just, and Carpenter (1994) focused on maintenance of multiple meanings. The relative importance of suppression and maintenance might depend on the linguistic context: suppression might be more important at a time point when the comprehender has enough information to resolve the ambiguity (e.g., following the sentence *"He dug with the spade,"* Gernsbacher et al.), and efficient suppression of an irrelevant meaning would be expected to result in more rapid integration of the relevant meaning (Gernsbacher et al.).

In contrast to suppression, maintenance might be more important during a time period when the comprehender does not have enough information available for ambiguity resolution. Miyake et al. (1994) examined the relationship between ambiguity resolution and working memory capacity (as measured by the reading span test, Daneman & Carpenter, 1980). In an initially neutral context (e.g., *"Since Ken really liked the boxer, he took a bus to the nearest pet store to buy the animal."),* Miyake et al. found that high-span readers did not exhibit longer reading times when they encountered disambiguating context that was inconsistent with the most frequent interpretation (e.g., when they encountered the region following the word "pet" in the above example). In contrast, mid- and low-span readers did exhibit longer reading times, suggesting that readers with a larger working memory (WM) capacity were able to maintain multiple interpretations over time. Mid-span readers no longer exhibited longer reading times when the distance between the ambiguous word and the disambiguating context was reduced. While this study suggests that high-span readers maintain multiple meanings until disambiguation occurs, it does not rule out the possibility that part of the effect of WM span on ambiguity resolution is actually due to differences in initial activation (e.g., variability based on the quality of lexical representations; Perfetti & Hart, 2001). For low-span readers, less-frequent meanings might never rise above threshold levels of activation.

Another alternative to maintenance theories is the idea that suppression or inhibition of less frequent meanings is important when disambiguating information is not available (e.g., Gunter, Wagner, & Friederici, 2003). Suppression might free up WM capacity that could be used to satisfy the competing demands of processing and storage that occur during language comprehension (Daneman & Carpenter, 1980). According to the suppression argument, high-span (HS) readers are likely to initially inhibit less frequent meanings of an ambiguous word, but are also able to quickly revise their initial interpretation when biasing contextual information is encountered. In contrast, low-span (LS) readers maintain multiple interpretations over time and are slow to inhibit the dominant meaning when this interpretation is inconsistent with biasing contextual information (Gunter et al.).

Effects of Syntactic/Thematic Integration

Taking a different approach, Peterson and Savoy (1994) have suggested that multiple meanings of an ambiguous word are maintained over time until there is sufficient syntactic or thematic information to force the selection of a meaning. In an earlier study, Seidenberg, Tanenhaus, Leiman, and Bienkowski (1982) argued that meaning selection takes place within 200 ms of the presentation of an ambiguous word, regardless of the availability of a higher-level structure. Seidenberg et al. (Experiment 1) found that a single meaning of an ambiguous prime was selected by 200 ms after the prime’s presentation, regardless of the presence of a complete (e.g., *If Joe buys the straw*) or incomplete (e.g., *If Joe puts the straw*) clause. However, despite the fact that a complete clause has not been provided in the second example, some types of syntactic information (noun, verb, and direct object) and thematic information (agent, theme, and patient) have been provided. The indirect object/thematic goal has not been provided, but the verb/theme might be a more crucial source of information. Thus, the results of this experiment do not rule out the possibility of a syntactic/thematic influence on ambiguity resolution.

Peterson and Savoy (1994) used a cross-modal priming procedure to investigate this possibility. Participants listened to active or passive Wh- questions containing an ambiguous word (e.g., *"Which bank did the woman see?"* or *"Which bank was seen by the woman?"*). In a Wh- question such as this, the ambiguous word is the underlying direct object and thematic patient, but its role in the sentence remains unclear until the occurrence of the verb, which occurs 750 ms (passive question) or 1,400 ms (active question) after the ambiguous word. In addition, the sentence stimuli did not provide biasing semantic or pragmatic information that could be used to aid meaning selection. Peterson and Savoy visually presented target words immediately after the end of a sentence or after an inter-stimulus interval (ISI) of 300 ms, and targets were named out loud by participants. Target words were related to the dominant (most frequent) meaning of the ambiguity (e.g., *money*), a subordinate (less frequent) meaning (e.g., *river*), or were unrelated. Immediately after the presentation of the verb, semantic priming occurred for both dominant- and subordinate-related targets, indicating that meaning selection had not yet occurred. Following a delay of 300 ms or more after the verb, priming occurred only for dominant-related targets, indicating that selection of the most frequent meaning had occurred after the verb was processed. Peterson and Savoy argued that, rather than being time-locked to the presentation of an ambiguous word, selection of a single meaning is time-locked to the point at which the word can be integrated into some higher-level structure, which does not occur until the verb is reached in these sentences.

Disadvantages of Semantic Priming Studies

Although the findings of Peterson and Savoy (1994) support the hypothesis that meaning selection is withheld when the syntactic/thematic context is incomplete, this study utilized the methodology of cross-modal semantic priming (Swinney, 1979), which involves the use of a reaction time (RT) task such as lexical decision or word naming. With these RT tasks, it is difficult to sample from numerous time points, since each sample requires the presentation of a target word and measurement of the participant's response to the target; because this has the effect of interrupting language processing, sampling can typically occur only once per trial. In order to conduct a more comprehensive exploration of the time course of ambiguity resolution, it is desirable to utilize a methodology that allows continuous sampling. Some lexical ambiguity studies have utilized such methodologies. For example, Gunter et al. (2003) recorded event-related potentials, and Duffy et al. (1988) recorded eye movements as participants read language stimuli containing an ambiguous word. Recently, eye tracking has been used in an experimental situation known as the *visual world paradigm,* which allows for an exploration of the interaction between auditory language comprehension and visual context (Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995).

Eye Tracking and the Visual World Paradigm

Visual world studies have found that eye movements to visual referents are closely tied to language processing. For example, Dahan, Magnuson, and Tanenhaus (2001, Experiment 2) presented a referent picture (e.g., *bed* or *bell)* along with three unrelated distractors (e.g., *sock, headphones,* and *knife*) on a computer monitor. On each trial, participants were instructed to move one of the pictures (using a computer mouse). When participants heard the name of a referent, they fixated referent pictures with high-frequency names (e.g., *bed*) more rapidly than those with low-frequency names (e.g., *bell*), demonstrating that eye fixation patterns are affected by properties of language that are not present in the visual scene (i.e., phonological competitors for *bell* were not actually presented).

Important concerns regarding the visual world paradigm have been identified by Tanenhaus, Magnuson, Dahan, and Chambers (2000). One of these concerns involves the nature of the *linking hypothesis* that specifies the connection between language comprehension and eye movements. Tanenhaus et al. have argued that spoken language activates “automated behavioral routines that link a name to its referent (p. 565).” Activation of these routines results in eye movements to relevant components of the visual context. Allopena et al. (1998) and Dahan et al. (2001) have provided convincing evidence for this linking hypothesis: fixations on visual images corresponded well with predicted fixations generated from the model of speech perception known as TRACE (McClelland & Elman, 1986).

Some visual world studies (e.g., Altmann & Kamide, 1999) have employed a version of the paradigm that involves *passive listening* (Cooper, 1974), in which participants are not required to execute an explicit response during viewing/listening. In a passive visual world experiment that investigated lexical ambiguity resolution, Huettig and Altmann (2004, Experiment 5) manipulated the context (neutral, subordinate-biasing, or dominant-biasing) preceding an ambiguous word (e.g., subordinate-biasing: “First, the welder locked up carefully, but then he checked the *pen* and suspected that it was damaged.”). Participants viewed a visual array containing four images: the dominant referent, the subordinate referent, and two unrelated distractor images.

The results were reported in terms of visual fixations at the onset of the ambiguous word, saccadic eye movements that occurred during the ambiguous word, and visual fixations at the offset of the ambiguous word. The pattern of fixations at the onset indicated that the contextual manipulations were successful – there was no preference for dominant or subordinate targets in a neutral context, but the appropriate picture was preferentially fixated in a biasing context. In the neutral context, saccades during the ambiguous word were more likely to be toward the dominant target than the subordinate target, but saccades were more likely to be toward the subordinate target than distractor images. In the biasing contexts, saccades were equally likely to be toward dominant and subordinate images (regardless of the nature of the biasing context), and saccades toward each type of referent were greater than saccades toward distractor images (supporting the exhaustive access model; Swinney, 1979). These results indicate that eye movements during a passive listening task can reflect the activation of multiple meanings, and that a preceding biasing context does not restrict activation to a single meaning. However, the correct (in a biasing context) or more frequent (in the neutral context) meaning was more likely than the incorrect or less frequent meaning to be fixated by the end of the word, suggesting that meaning selection occurs quickly once the ambiguous word can be integrated with contextual information.

Although Huettig and Altmann's work on lexical ambiguity (2004, Experiment 5) involved the presentation of images that depicted the dominant and subordinate referents (e.g., an image of a writing utensil and an image of an animal enclosure on the "pen" trial), other visual world studies have involved the presentation of images that are semantically related to a referent. For example, Huettig and Altmann (2005) found that saccades toward categorically-related pictures occurred more often than saccades to unrelated distractors (e.g., saccades to an image of a trumpet occurred when the word "piano" was heard). In other work, similar effects based on semantic association have been observed (Cooper, 1974; Moores, Laiti, & Chellazi, 2003; Yee & Sedivy, 2001). For example, Yee and Sedivy found that participants made saccades to an image of a key when they heard the word "lock."

The current study utilizes the passive visual world paradigm to investigate the time course of ambiguity resolution. In most of the experiments, participants viewed an array containing one dominant-related picture (DRT), one subordinate-related picture (SRT), and two unrelated pictures. The dependent variable of interest was the probability of fixation on a given clip-art picture. If a word's dominant or subordinate meaning has been activated in memory, then the probability of fixation on a clip-art picture that is related to that meaning should be higher than the probability of fixation on an unrelated clip-art picture. The target pictures were designed to represent semantic associates of ambiguous words taken from the Nelson, McEvoy, Walling, and Wheeler (1980) homograph norms or the Twilley, Dixon, Taylor, and Clark (1994) homograph norms. However, many of the pictures could plausibly be considered to be actual referents for the dominant or subordinate meaning of a given ambiguous word (53 % of dominant-related targets and 59% of subordinate-related targets are plausible depictions of the referent).

This study explores the time course of ambiguity resolution, focusing on the effects of meaning frequency, biasing context, working memory capacity, and syntactic/thematic integration. In addition, this study explores questions related to the visual world paradigm that have not been fully explored. One general question is related to the presentation of multiple related targets in the visual array. To what extent does this aspect of the procedure inhibit fixations to an individual related target (i.e., what is the effect of competition between related targets)? Another general question is concerned with the nature of the stimuli that can be used within the visual world paradigm. Can words be used as visual stimuli, or is it necessary to utilize pictures or objects? Two more questions have been motivated by the possibility that the passive visual world paradigm is not completely passive: how do results obtained under passive and active instructions differ, and how are eye movements influenced by the participant's level of awareness and strategy use?

Experiment 1: Passive Picture Viewing

In Experiment 1, Wh- question stimuli similar to those used by Peterson and Savoy (1994; e.g., *"Which diamond did the man like?*) were utilized (see Figure 1 for the images used with this stimulus item). Although the questions were non-biasing, each question was followed by a disambiguating reply sentence (e.g., *"The one with the rubies."* or *"The one with the bleachers."*). Thus, continuous sampling of visual fixations during and after the question sentence allowed for an evaluation of the hypothesis that ambiguity resolution is withheld until after syntactic or thematic integration. Sampling of visual fixations after the disambiguating reply allowed for an examination of the effects of late-occurring biasing information.

In the initially neutral context being utilized, it was predicted that the pattern of fixations would indicate activation of both the dominant meaning and a subordinate meaning (Seidenberg et al., 1982). Dominant meaning activation was expected to be stronger and more rapid than subordinate meaning activation (Simpson & Burgess, 1985). Following initial meaning activation, maintenance and suppression theories make different predictions regarding the effects of WM span. If HS participants maintain multiple meanings over time (Miyake et al., 1994), then they would demonstrate above-baseline fixation of both the DRT and SRT until selection is triggered by syntactic integration when the verb is processed (Peterson & Savoy, 1994), or until biasing context leads to selection when the disambiguating reply is processed. Low-span participants would not be expected to maintain the subordinate meaning over time, and would therefore be expected to fixate the contextually-consistent SRT more slowly than HS. Alternatively, if HS participants quickly suppress the subordinate meaning in the absence of contextual support but are also able to rapidly revise their interpretation when the subordinate meaning is supported (Gunter et al., 2003), then fixation of the SRT would initially decline over time, but would rapidly increase if the subordinate meaning were supported by the reply. Low-span participants would fixate both the DRT and SRT over time, and poor suppression mechanisms would result in continued fixation of the DRT when it was inconsistent with the reply.

Method

Participants. Sixty-two undergraduate students from the University of Missouri-Columbia participated in exchange for course credit. All participants were right-handed (determined through self-report), had normal vision or wore contacts, and were native speakers of English.

Apparatus. An Applied Science Laboratories Model 504 Eye-Tracking System was used in all eye-tracking experiments. The eye-tracking system consists of a pan/tilt infrared camera and a control unit, sampling at 60 Hz. The control unit calculates visual fixations based on the position of the pupil, the position of the corneal reflection, and data from a calibration routine. Accuracy is within one degree, and precision is within half of one degree. The vertical and horizontal coordinates of each fixation were recorded on disk during each time sample, and these coordinates were used to determine participants' fixations on entities such as related pictures, unrelated pictures, and the fixation cross.

Visual stimuli were presented on a 21” monitor, and auditory stimuli were played on stereo speakers placed next to the monitor. Head movements were virtually eliminated through the use of a chin rest.

Materials. Thirty-two ambiguous words that are both homographs and homophones were selected from six overlapping sets of norms: Cramer (1970; 7 words); Gawlick-Grendell and Woltz (1994; 7 words); Kausler and Kollasch (1970; 3 words); Nelson, McEvoy, Walling, and Wheeler (1980; 30 words); Twilley, Dixon, Taylor, and Clark (1994; 32 words); Wollen, Cox, Coahran, Shea, and Kirby (1980; 5 words). Twenty-seven of these 32 words were also utilized by Peterson and Savoy (1994). In the current study, the proportion of responses accounted for by the dominant meaning and a subordinate meaning were averaged across the six sets of norms to arrive at an average proportion for each meaning type. An ambiguous word was selected if it satisfied the following conditions: the most frequent meaning accounted for at least 60% of the responses, and it was possible to obtain clip-art images that were related to the dominant meaning and a subordinate meaning. For the 32 ambiguous words selected, the dominant meaning accounted for 61% to 95% of the responses (M = 81%, SD = 10%); the subordinate meaning accounted for 0% to 33% of the responses (M = 12%, SD = 10%).

Sixty-four critical clip-art images and 112 filler clip-art images were selected. The images were obtained from commercial or web-based clip-art collections. Each clip-art image was converted to grayscale and, if necessary, modified in order to satisfy size restrictions (each image was between 100 and 250 pixels in both the horizontal and vertical dimensions). Each clip-art image was presented twice during the experiment. All images were presented on a 21” monitor, two degrees from a central fixation cross, and each image subtended less than four degrees of arc.

Thirty-two critical and 56 filler sentence-reply pairs were constructed, and each question-reply pair was digitally recorded as a single sound file. On each critical trial, a Wh- question similar to those used by Peterson and Savoy (1994; e.g., *“Which diamond did the man like?*) was utilized (see Appendix A for the critical stimuli). Each question was followed by a disambiguating reply sentence that was consistent with one of the meanings of the ambiguous word (e.g., *“The one with the rubies.”* or *“The one with the bleachers.”*). The filler auditory stimuli were similar to the critical stimuli, except that the question did not contain an ambiguous word. For all auditory stimulus pairs, a male speaker and a female speaker recorded the stimuli. On half of the stimulus pairs, the male spoke the question and the female spoke the reply, whereas on the other half of the stimulus pairs the order was reversed.

Using the Nelson, McEvoy, and Schreiber (1998) word association norms, associative relationships between each ambiguous word and its dominant- and subordinate-related targets were obtained (using the target labels). Relationships between each disambiguating word (e.g., “rubies” or “bleachers”) and the corresponding target were also obtained from the Nelson et al. word association norms, or were estimated using ratings made by 28 undergraduate students, who participated in exchange for course credit. Compared to SRT's (*M* = 2.94%, *SD* = 4.84%), DRT's (*M* = 26.29%, *SD* = 28.57%) were more strongly associated with the ambiguous words [$t(31) = 4.62$, $p < .001$, $\eta^2 = .41$], which was not surprising since the picture stimuli were chosen based on word associations from homograph norms. Importantly, associations between disambiguating replies and related targets were weak (dominant: *M* = 1.88, *SD* = 3.77; subordinate: *M* = 7.68, *SD* = 22.08), and there was no significant difference in associative strength between dominant and subordinate reply-target pairs, $t(31) = -1.46$, $p = .15$, $\eta^2 = .06$. Therefore, it is not likely that fixations of related targets were driven by simple associations between the biasing words and the targets, nor is it likely that differences in associative strength produced greater fixation rates for a specific target type.

The reading span test (Daneman & Carpenter, 1980) was administered in order to arrive at an estimate of each participant’s working memory span. Beginning with two-sentence sets and continuing up to six-sentence sets (depending on performance), participants read 13- to 16-word sentences out loud, and were then asked to recall the final word of each of the sentences from that set. If the sentence-final words were correctly recalled for three of the five sets on a given level of difficulty, then the participant advanced to the next level. Half credit was given for correct recall of two out of the five sets from a level (e.g., correct recall of two sets on level three was scored as a 2.5).

Procedure. Before eye tracking took place, the reading span test was administered, and participants were familiarized with the clip-art pictures used in the experiment. Each picture appeared on a computer monitor and was identified for the participants.

Participants were given a recognition test for a random subset of these pictures. Following the picture familiarization, participants were given instructions for the eye-tracking segment of the experiment, and several (two to four) practice trials were conducted to ensure that participants were familiar with the procedure. Practice trials were similar to filler trials.

There were 32 critical trials and 56 filler trials. During each critical trial, participants listened to a Wh- question-reply pair (containing an ambiguous word) while viewing a visual array that contained two related clip-art images (one related to the dominant meaning and one related to a subordinate meaning) and two unrelated clip-art images (see Figure 1). Each unrelated image served as a related target during a different critical trial. Filler trials differed from critical trials in the following respects: the question sentence did not contain an ambiguous word, and all of the clip-art pictures were unrelated. Like critical images, each filler image appeared twice during the experiment.

The stimulus timeline for Experiment 1 is presented in Table 1. The sequence of events was similar to that used by Allopena et al. (1998). At the beginning of each trial, four clip-art images appeared on the screen. Participants were instructed to briefly look at each of the pictures. Three seconds after the pictures appeared, a tone was sounded. Participants were instructed to briefly fixate the central fixation cross when the tone was heard, and then continue to look at the pictures however they wished to do so (i.e., they were not given specific instructions about how they should view the pictures). One-and-a-half seconds after the onset of the tone, the question sentence began. After a brief (about 500 ms) interval following the end of the question, the reply began. The pictures remained on the screen for approximately two seconds after the end of the reply sentence.

Following a three-second delay, the next trial began. After each block of trials, participants were given a true/false recognition test over some of the sentences from the previous block.

Following the completion of the experiment, participants were asked several questions regarding their awareness of related targets, the number of related targets present, and whether or not they intentionally looked at related targets. If participants indicated that they noticed the presence of related targets, said that there were one or two (but not more) related targets present, and indicated that they intentionally fixated related targets, they were classified as aware/intentional (AI) participants.

Data Analysis. If individual fixations within a quadrant were greater than two degrees away from the midline and the meridian, they were scored as being on the picture within that quadrant. Blinks, saccades, and fixations on the central fixation cross were also identified. Fixation probabilities were calculated within participants, then averaged across participants for each picture type.

Results and Discussion

The overall fixation probabilities are presented in Figure 2 (events such as saccades, blinks, and center cross fixation are not depicted, and thus the probabilities do not sum to 1). In this figure and those that follow, the green line represents the average probability of fixating an unrelated target on critical trials, and this probability is treated as a baseline. If the fixation probability for a given type of related target is significantly greater than this baseline (determined through inspection of 95% confidence intervals, which are represented by the dotted lines), then this type of target has been preferentially fixated, and it can be inferred that the meaning related to the target type has been activated.

Comparisons were also made during specific time windows through the use of two sets of orthogonal contrasts. Prior to the onset of the disambiguating reply, the effects of relatedness (related vs. baseline) and target type (dominant vs. subordinate) were examined using one set of orthogonal contrasts. Following the onset of the reply, the effects of relatedness (related vs. baseline) and the reply X target interaction (consistent dominant vs. inconsistent subordinate, consistent subordinate vs. inconsistent dominant) were examined using another set of orthogonal contrasts.

As can be seen in Figure 2, the DRT was preferentially fixated by 2500 ms, roughly 400 ms after the offset of the ambiguous word. In contrast, the SRT was preferentially fixated approximately 200 milliseconds after the DRT. This finding is consistent with previous evidence that the dominant meaning is activated more quickly in a neutral context (e.g., Simpson & Burgess, 1985). Fixation of the DRT was also stronger than SRT fixation between the onset of the ambiguous word and the offset of the sentence, $F(1, 244) = 20.1$, $p < .001$. SRT fixation remained weaker than DRT fixation over time, and was near baseline until approximately 3750 ms.

The effect of the disambiguating information provided by the reply (e.g., "rubies" or "bleachers") was rapid; by the offset of this information (at 4750 ms), fixations began to decline if the picture was inconsistent with the reply, regardless of meaning frequency. Between 4750 and 5000 ms, fixations of the consistent SRT and inconsistent DRT were not significantly different, $F(1, 244) = 2.68$, $p = .10$. Between 5000 ms and 5250 ms, consistent SRT fixation became greater than inconsistent DRT fixation, $F(1, 244) = 25.06$, $p < .001$. Fixation of the consistent SRT eventually overlapped with fixation of the consistent DRT.

Figures 3 and 4 depict fixations for HS and LS participants, respectively. Participants who received a reading span score greater than the median (2.5) were classified as HS (n = 25); those with scores equal to or below the median were classified as LS (n = 37). No effects of span were significant. As can be seen in Figures 3 and 4, HS and LS had a similar pattern of results, matching the overall results described above.

Participants were also classified based on their awareness of related targets and strategy use, as described in the procedure section. Thirty-four participants met the aware/intentional criteria (HS were not more likely to meet the criteria, $\chi^2(1, N = 62) = 1.99, p = .16$). The effect of awareness/intention interacted with the pattern of fixations during the time windows examined above [ambiguity offset to sentence offset: $F(4, 240) = 2.96, p < .05$; 4750 to 5000 ms: $F(4, 240) = 11.11, p < .01$; 5000 to 5250 ms: $F(4, 240) = 11.16, p < .01$]. Fixation probabilities for participants who met the criteria are presented in Figure 5. Although the time course of fixations for these participants is similar to the overall results, it can be seen that fixation probabilities for related targets are larger. In contrast, fixation probabilities for the 28 unaware/unintentional (UU) participants are much lower (Figure 6). Interestingly, preferential (above baseline) fixation of the DRT is only slightly slower for these participants, but DRT fixation continues to overlap with SRT fixation over time, while SRT fixation overlaps with the baseline until a time point following the consistent disambiguating reply. Thus, the initial dominant meaning selection and slow subordinate meaning activation seen in AI participants appear to be weaker in UU participants, suggesting that results obtained through the passive visual world paradigm are influenced by participants' awareness and strategy use, calling the passivity of the paradigm into question.

The results of Experiment 1 fail to support the argument that meaning selection is withheld until the verb is encountered in this type of sentence context (Peterson & Savoy, 1994). Instead, the dominant meaning was quickly and strongly activated after the ambiguous word was processed, whereas the subordinate meaning was activated more slowly, and remained near baseline for an extended period. The results also fail to provide evidence that ambiguity resolution is influenced by working memory capacity. Both span groups demonstrated strong activation of the dominant meaning and weak activation of the subordinate meaning, as well as rapid meaning revision when the subordinate meaning was consistent with the disambiguating reply (cf. Gunter at al., 2003; Miyake et al., 1994). Although fixations were not influenced by working memory span, fixations were influenced by awareness and strategy use. Experiment 2 explores this issue further.

Experiment 2: Active Picture Viewing

The purpose of Experiment 2 was to investigate the effects of awareness and specific strategy use on participants' visual fixations. Although participants in Experiment 1 were not instructed to fixate related images, many of them indicated that they were aware of the related images and intentionally fixated them, and this behavior substantially increased the probability of fixating related targets; it also led to earlier fixation of subordinate-related targets. Since many participants were already employing the strategy of fixating related targets, this leads to the question of how fixations might differ if participants were given specific instructions to fixate the most closely related image as quickly as possible. With these explicit instructions, it was predicted that the fixation rates for related targets would be similar to those observed for the AI participants from Experiment 1. However, it was also predicted that initial fixation of the DRT and the eventual revision of this frequency-based interpretation would both occur more quickly under explicit instructions, compared to spontaneous awareness and strategy use.

Method

Participants. Sixty-four undergraduate students participated in exchange for course credit. Participants met the same criteria as in Experiment 1.

Materials. The materials were identical to Experiment 1.

Procedure. Participants were informed that one or more of the pictures would be related to the sentence stimuli on some of the trials, and they were instructed to fixate the most closely-related image as quickly as possible. All other aspects of the procedure were identical to Experiment 1.

Results and Discussion

Compared to the overall results of Experiment 1, participants under explicit instructions demonstrated two main differences (see Figure 7). First, there was an enhancement effect for the contextually-consistent DRT. The effect of the dominant reply was greater for the current experiment [mean DRT fixation = .53, mean SRT fixation = .13, $F(1, 252) = 242$, $p < .001$, $\eta^2 = .49$] than for Exp. 1 [mean DRT fixation = .30, mean SRT fixation = .15, $F(1, 248) = 92.4$, $p < .001$, $\eta^2 = .28$]. Second, participants revised their initial interpretation more slowly when the context was consistent with the subordinate meaning. The overall fixation results of Exp. 1 indicated that the consistent SRT was fixated at a greater rate than the inconsistent DRT by the 5000-5250 ms time window. In the current experiment, participants fixated the inconsistent DRT at a greater rate within this time window, $F(1, 252) = 11.78$, $p < .001$. By 5250-5500 ms, the consistent SRT was fixated at a greater rate, $F(1, 252) = 4.48$, $p < .05$. Thus, explicit instructions did not result in faster fixation of related targets compared to passive-viewing instructions. Instead, explicit instructions enhanced fixation of the initially-selected DRT, including when the DRT was inconsistent with the disambiguating reply. These findings are consistent with Simpson and Burgess (1985), who argued that selection processes are driven by attention, but also argued that these processes are nonetheless difficult to control consciously.

Thirty participants were above the median reading span score, which was again 2.5. The results for HS and LS are depicted in Figures 8 and 9, respectively. The pattern of results was similar for the two groups, and no significant effects were found.

Experiment 3: Passive Word Viewing

Although visual world studies typically involve the use of images or actual objects as the visual stimuli, it is unclear how the results of these eye-tracking studies would change if words were used as the visual stimuli. Does the linguistic or orthographic world affect eye movements in the same way as other aspects of the visual world (i.e., images or objects)? In the current passive-viewing experiment, each picture stimulus was replaced with a corresponding word. It is possible that the results will be similar to those observed in the passive picture-viewing experiment (Exp. 1); on the other hand, the findings of Federmeier and Kutas (1999; 2001) suggest that some modality-specific differences in semantic processing are likely to be observed. In two studies involving event-related potentials, Federmeier and Kutas examined the effects of contextual constraint (high or low) and categorical relatedness on the semantic processing of sentence-final words or pictures. For example, when the word “lion” was expected based on a strongly or weakly constraining context, a word from the same semantic category (“tiger”) or a different category (“penguin”) was presented. Relatedness and constraint interacted differently for words and pictures. Unexpected words from the same category were more difficult to process under low constraint than under high constraint. In contrast, unexpected pictures from a different category were more difficult to process under high constraint than under low constraint. Thus, modality-specific differences in semantic processing have been observed between pictures and words, although similarities also exist (e.g., the main effect of categorical relatedness was the same for words and pictures).

Method

Participants. Sixty-three undergraduate students from the University of Missouri participated in exchange for course credit. Participants met the same criteria as in previous experiments.

Materials. Each picture stimulus was replaced with a corresponding word. In most cases, the word was the label that had been used during picture familiarization. In some cases, the word was changed to a synonym to control for differences in word length. All words were 3-8 letters long. Similarly to the picture stimuli, associative relationships between each ambiguous word and its dominant- and subordinate-related target words were obtained using the Nelson et al. (1998) word association norms. Relationships between each disambiguating word (e.g., “rubies” or “bleachers”) and the corresponding target word were also obtained from the Nelson et al. word association norms, or were estimated using ratings made by 28 undergraduate students, who participated in exchange for course credit. Compared to SRT's (*M* = 2.42%, *SD* =

4.67%), DRT's (*M* = 20.34%, *SD* = 21.7%) were more strongly associated with the ambiguous words, $t(31) = 4.78$, $p < .001$, $\eta^2 = .42$. As with the picture stimuli, associations between disambiguating replies and related target words were weak (dominant: *M* = 1.95, *SD* = 3.85; subordinate: *M* = 7.85, *SD* = 22.05), and there was no significant difference in associative strength between dominant and subordinate reply-target pairs, $t(31) = -1.48$, $p = .15$, $\eta^2 = .07$.

Procedure. The procedure was identical to Experiment 1, except that participants were not familiarized with the words before eye tracking (the words did appear on the screen for three seconds before each trial).

Results and Discussion

The overall results are presented in Figure 10. Preferential fixation of the DRT was slower than in the picture-viewing experiments, occurring at approximately 2750 ms. Fixation of the SRT overlapped with the baseline until the consistent SRT was preferentially fixated following the reply, whereas earlier fixation of the SRT was observed in the picture-viewing experiments. Although the consistent SRT was eventually fixated at a rate greater than the inconsistent DRT, selection of the subordinate meaning occurred during a later time window in the current experiment [5000 to 5250 ms: $F(1, 248) = .19$, *ns*; 5250 to 5500 ms: $F(1,248) = 10.3$, $p < .001$].

Since participant awareness and strategy use proved to be important in the passive picture-viewing experiment (Exp. 1), these factors were also examined in the current experiment. Only 17 of the 63 participants met the aware/intentional criteria; compared to 34 out of 62 participants in Exp. 1, participants in the current experiment were less likely to meet the criteria, $\chi^2(1, N = 125) = 13.93$, $p < .001$. Results for aware participants are presented in Figure 11. Awareness interacted with target type [ambiguity onset to sentence offset: $F(4, 244) = 5.41$, $p < .01$] and the reply type [4500 to 7000 ms: $F(4, 244) = 11.23$, $p < .001$]. Compared to the overall results, AI participants fixated related targets at a greater rate, and consistent targets were selected more strongly. In addition, there was significant fixation of the SRT prior to the onset of the reply. UU participants (Figure 12) preferentially fixated the DRT, but fixation of the SRT never rose above baseline. Following the reply, the consistent DRT was preferentially fixated at first, but eventually overlapped with the inconsistent SRT. Thus, as with picture viewing, awareness and strategy use have strong effects on the fixation of target words. However, the effects are not exactly the same: although UU participants fixated related targets at a lower rate for both types of visual stimuli, UU participants viewing words were less likely to fixate the SRT, and they were less likely to demonstrate strong selection of either meaning following the reply.

Twenty-five participants were above the reading span mean of 2.5. Although HS and LS demonstrated similar patterns of fixations, HS were more likely than LS to meet the awareness criteria, $\chi^2(1, N = 63) = 13.37$, $p < .001$. Nevertheless, there were no significant interactions between span and any other variable.

The results of this experiment indicate that words are fixated differently from pictures in the passive visual world paradigm, but this finding is mitigated by the lower rate of awareness and strategy use in the current experiment. The lower rate may have been caused by the use of words rather than pictures, or the participants in the current experiment might have been different from those in Experiment 1. The former explanation is more likely - the participants in the two experiments were drawn from the same population of Psychology 1 students, during the same academic year. Although HS participants were more likely to meet the awareness criteria in the current experiment, whereas they were not in Exp. 1, the proportion of HS participants was identical in the two experiments (.40). Thus, it appears that the lower rate of awareness and strategy use in the current experiment is due to the type of visual stimuli used. Some have suggested that semantic activation does not occur automatically when words are perceived, although others have disputed this idea (see Neely & Kahan, 2001, for a review). If the meaning of a word is not activated as it is viewed passively, then participants would be less likely to notice relationships between the auditory and visual stimuli. It remains to be seen if the differences observed between the two types of visual stimuli are simply due to different rates of awareness and strategy use, or if differences would still be observed when explicit instructions are utilized.

Experiment 4: Active Word Viewing

Compared to passive picture viewing, passive word viewing resulted in lower fixation rates for related targets and delayed fixation of the SRT. However, participants in the passive word-viewing experiment were less likely to intentionally fixate the related words, and those that intentionally fixated related words demonstrated greater fixation rates and earlier fixation of the SRT. These results suggest that words might be fixated similarly to pictures if explicit instructions were utilized; this prediction was tested in the current experiment.

Method

Participants. Forty-two undergraduate students from the University of Missouri participated in exchange for course credit. Participants met the same criteria as in previous experiments.

Materials. The stimuli from Experiment 3 were utilized.

Procedure. The procedure was identical to Experiment 3, except that participants were given explicit instructions. Participants were informed that one or more of the words would be related to the sentence stimuli on some of the trials, and they were instructed to fixate the most closely-related word as quickly as possible.

Results and Discussion

The results are depicted in Figure 13. Compared to active picture viewing (Exp. 2), several differences can be observed: 1) The DRT is preferentially fixated more slowly by approximately 150 ms. 2) The SRT is fixated at a lower rate prior to the consistent reply. 3) Following the subordinate-consistent reply, SRT fixation became greater than DRT fixation during a later time window [6250 ms to 6500 ms: $F(1, 164) = 1.77$, $p = .18$; 6500 to 6750 ms: $F(1, 164) = 5.55$, $p < .05$], indicating that meaning revision occurred approximately 1250 ms later in the current experiment. Meaning revision was also approximately 1250 ms slower than when a passive word-viewing procedure was used in Exp. 3. Thus, as with picture stimuli, using explicit instructions results in slower meaning revision.

Twelve participants were above the reading span median of 2.5. No effects of span were observed.

The results of this experiment confirm the hypothesis that pictures and visual words are fixated differently in the visual world paradigm, even when explicit instructions are used. The most striking difference between words and pictures is the initially weak activation of the subordinate meaning when words are utilized. It remains unclear why this difference would occur. Although the ambiguous words were more strongly associated with the dominant-related target words compared to the subordinate-related target words, this was also the case for dominant-related pictures compared to subordinate-related pictures. Furthermore, the associations between ambiguous words and targets were not significantly different between the two sets of stimuli (dominant: M = 26.29% for pictures, 20.34% for words, $t(31) = 1.56$, $p = .13$; subordinate: M = 2.94% for pictures, 2.42% for words, $t(31) = 1.42$, $p = .17$). The associations between the disambiguating replies and the SRT's were also comparable between the two experiments (pictures: M = 7.67%; words: M = 7.85%; $t(31) = -.45$, $p = .65$, $\eta^2 = 0$).

Another possibility is that the picture stimuli were more likely to be taken as referents for the ambiguous words. Although the target words in Experiments 3 and 4 were never identical to the ambiguous words, some of the targets were synonyms for the ambiguous words (e.g., the ambiguous word "vault" and the target word "safe"), whereas other targets were members of a category denoted by the ambiguous word (e.g., the ambiguous word “game” and the target word “chess”). In contrast, other targets (e.g., "lock") were not synonyms or category members, but were associated with the corresponding ambiguous word (e.g., "key"). Target words that were synonyms or category members were identified and considered to be plausible referents for the ambiguous word. Compared to the corresponding picture stimuli, dominant target words were less likely to be referents, $\chi^2(1, N = 64) = 6.25$, $p = .01$, but subordinate target words were not, $\chi^2(1, N = 64) = 1.63$, $p = .20$. Thus, stimulus characteristics do not explain why SRT's were fixated less often in the word experiments.

Instead, the differences observed between pictures and words are likely due to the more direct route to meaning that is made available by pictures (Federmeier & Kutas, 2001). For example, a picture of a tennis racket is fairly unambiguous (provided that the picture is not perceptually ambiguous), and the tennis racket is unlikely to be mistaken for another object, especially if the picture is a familiar one. In contrast, words are often ambiguous. The target word "racket" could refer to a tennis racket, or it might refer to a criminal enterprise or a loud noise.

Another explanation for the differences observed between pictures and words is that visual words are not often referred to by spoken language. When spoken language refers to the visual world, it typically refers to objects or images that one's eyes are drawn to automatically (Tanenhaus et al., 2000); spoken language does not typically refer to visual representations of words. Compared to objects or images, this difference might result in a smaller probability of success when seeking out target words that are related to the semantic context provided by spoken language.

Experiment 5: Effects of Target Competition

One potential shortcoming of the visual world paradigm is the possibility that presenting one or more related targets could alter normal patterns of meaning activation and selection. Although the passive-viewing experiments in the current study were designed in such a way that controlled processing of semantic relationships should be less likely (including a low proportion of related trials [.36]), results from the post-experiment questionnaire indicated that many participants did engage in controlled processing, perhaps increasing the probability that meaning activation patterns were altered by the presentation of related targets. Presenting a related target might enhance meaning activation, or it could have the effect of inhibiting activation of another meaning.

Huettig and Altmann (2004) have explored the possibility that the presentation of a related target could result in enhanced activation for a meaning that would otherwise be weakly activated or not be activated at all. As discussed previously, these investigators observed saccades to dominant referents within a subordinate-biasing context. It is possible that the dominant meaning would not typically be activated in such a context, but was activated in this experiment because an image depicting the dominant referent was presented to participants. Through an additional manipulation, Huettig and Altmann provided evidence against this interpretation. In the subordinate-biasing condition, a similar array of images was presented, except that the dominant referent was replaced by a competitor with similar perceptual features (e.g., a needle instead of an ink pen). The pattern of results was highly similar to the pattern observed when both the dominant and subordinate referents were presented. Thus, it seems that activation of the dominant meaning (in a subordinate-biasing context) is not dependent on the presentation of the dominant referent, but can instead occur in the absence of the referent (note that these results do not distinguish between predictions made by the exhaustive access model [Swinney, 1979] and predictions made by the reordered access model [Duffy et al., 1988]). However, it remains possible that the perceptual features of the competitor activated concepts related to these features, resulting in activation of the dominant meaning (Huettig & Altmann).

In contrast to the possible enhancement produced by the presentation of a related target, another possibility is that presenting one type of related target might inhibit activation of another meaning or fixation of another target type. Experiments 1-4 involved the presentation of two related targets per trial. This aspect of the procedure may have resulted in artificial levels of target fixation – either the dominant or subordinate target may have been fixated less often because a competing related target was also present. For example, competition among targets may have initially suppressed the probability of fixating the SRT, causing activation of the subordinate meaning to appear to be slower or weaker than it actually was. If competition among the targets reduced initial fixation probabilities, then presenting a single related target on each trial should result in larger or more rapid fixations for a related target. Given the more rapid fixation of the DRT observed in previous experiments, it is likely that SRT fixation would benefit more from this change in procedure.

In the current experiment, the initially-neutral auditory stimuli from Experiment 1 were used (e.g., *"Which diamond did the man like?"* followed by *"The one with the rubies."* or *"The one with the bleachers."*). To determine the extent to which target fixation in the two-target context reflects "pure" meaning activation that is uninfluenced by the presence of another target, only one related target picture was presented on each trial, along with three unrelated distractor images. In half of the critical trials, the related image was consistent with the disambiguation; in the other half, it was inconsistent (e.g., participants saw a picture of a baseball, but heard *"The one with the rubies."*).

It was predicted that the pattern of fixations prior to the disambiguating information would be similar to the pattern observed in Experiment 1, although the overall rate of fixation might be expected to increase. These findings would support the hypothesis that the initial pattern of fixations is primarily driven by spontaneous meaning activation (i.e., meaning activation that results from the processing of the auditory ambiguous word), and that competition among related targets does not have a significant impact on meaning activation. Following the disambiguating information, it was predicted that a contextually-inconsistent related target would generally be fixated at a greater rate than in Experiment 1, given initial activation of the inconsistent meaning and the lack of a contextually-consistent target in the current experiment.

Method

Participants. Eighty-one undergraduate students from the University of Missouri-Columbia participated in exchange for course credit. Participants met the same criteria as in the previous experiments.

Materials. The materials were identical to those used in Experiment 1.

Procedure. The procedure was identical to that of Experiment 1 (passive picture viewing), except that only one related target was presented during each trial, along with three filler images. As in previous experiments, each unrelated image that was presented during a critical trial also served as a related target during a different critical trial. Every stimulus image appeared twice during the experiment. The reply sentence was inconsistent with the related target on half of the critical trials (i.e., the DRT was presented, but participants heard the subordinate-biased reply, or vice versa).

Results and Discussion

As can be seen in Figure 14, which presents the overall fixation probabilities, preferential fixation of the SRT coincided with preferential fixation of the DRT. This finding is in contrast to the previous two-target experiments, in which the DRT was preferentially fixated earlier than the SRT, indicating earlier activation of the dominant meaning. However, after an initial period of overlapping fixations, DRT fixation became higher than SRT fixation, which is consistent with the initial fixation rates observed prior to the disambiguating reply in previous experiments. For example, during the time window prior to the onset of the disambiguating information (4000 to 4250 ms), DRT fixation was greater than SRT fixation, $F(1, 320) = 27.2$, $p < .001$. Thus, competition between related targets appears to slow initial fixation of the SRT, but it has less of an effect on the overall pattern of DRT and SRT fixations prior to the reply.

Following the disambiguating information, fixation of the consistent SRT increased. Fixation of the consistent SRT was greater than inconsistent DRT fixation between 5250 and 5500 ms [5000 to 5250 ms: $F(1, 320) = .07$, *ns*; 5250 to 5500 ms: $F(1, 320) = 2.49$, $p < .05$], approximately 250 ms slower than in Exp. 1. Between 5250 and 7000 ms, both the consistent DRT and consistent SRT were fixated at a greater rate than the corresponding inconsistent targets [dominant selection: $F(1, 320) = 20.95$, $p < .001$, $\eta^2 = .06$; subordinate selection: $F(1, 320) = 10.14$, $p < .01$, $\eta^2 = .03$]. Although the contextually-consistent meaning was selected, the effects of context were weaker than in Exp. 1 [Exp. 1 dominant selection: $F(1, 244) = 84.2$, $p < .001$, $\eta^2 = .26$; Exp. 1 subordinate selection: $F(1, 244) = 92.9$, $p < .001$, $\eta^2 = .28$].

These findings suggest that suppression of an inconsistent meaning may be more difficult in the one-target visual context. If the relationship between working memory span and ambiguity resolution is due to more efficient suppression or inhibition mechanisms among HS (Gunter et al., 2003), then HS might be more likely to suppress the inconsistent meaning (27 participants were above the reading span median of 2.5). However, span did not interact with context, and there were no other significant effects of span. The fixation probabilities for HS and LS can be seen in Figures 15 and 16.

The onset and absolute rate of preferential fixations prior to the disambiguating reply indicate that preferential fixations in the two-target visual context (used in previous experiments) are not driven solely by spontaneous meaning activation. However, the overall pattern of fixations during this time period was similar to Experiment 1, suggesting that fixations in the two-target context typically reflect relative meaning activation, if not absolute rates of meaning activation.

It is possible that it is actually the one-target procedure used in the current experiment that artificially influences fixation rates or meaning activation itself. Following the disambiguating reply, meaning revision was slower compared to Exp. 1, and the effects of context were weaker. These results suggest that inhibition of a contextually-inappropriate meaning is more difficult when an image related to that meaning is present in a visual scene, but an image related to the contextually-appropriate meaning is not present.

Experiment 6: Earlier Biasing Context

The purpose of Experiment 2 was to determine if the pattern of meaning activation that occurred in Experiment 1 could be altered by earlier biasing information. The auditory stimuli were again Wh- questions and replies, but biasing information occurred in the question sentence, and the reply was consistent with this information (e.g., *"Which diamond was very valuable? The one with the rubies."* or *"Which diamond was very overgrown? The one with the bleachers."*). One would expect that the effect of context would be observed at an earlier time point than it was in the first experiment.

Method

Participants. Sixty undergraduate students from the University of Missouri-Columbia participated in exchange for course credit. Participants met the same criteria as in previous experiments.

Materials. The materials used in Experiment 6 were identical to those used in previous picture-viewing experiments, with the exception of the auditory stimuli (see Appendix B). Each critical question contained disambiguating information, and was followed by a reply that was consistent with that information (e.g., *"Which diamond was very valuable? The one with the rubies."* or *"Which diamond was very overgrown? The one with the bleachers."*). Filler auditory stimuli were similar to the critical stimuli, but did not contain an ambiguous word.

Relationships between each disambiguating word and the corresponding target were obtained from the Nelson et al. (1998) word association norms, or were estimated using ratings made by 28 undergraduate students, who participated in exchange for course credit. For the first disambiguating word (e.g., "valuable" and "overgrown"), associations between disambiguating replies and related targets were weak (dominant: M = 3.5%, SD = 17.7%; subordinate: M = 0.20%, SD = 0.69%), and there was no significant difference in associative strength between dominant and subordinate reply-target pairs, $t(30) = 1.02$, $p = .32$, $\eta^2 = 0$ (one reply-target association was unknown). For the second disambiguating word (e.g., "rubies" and "bleachers"), associations between disambiguating replies and related targets were again weak (dominant: M = 1.55%, SD = 3.46%; subordinate: M = 7.53%, SD = 22.15%), and there was no significant difference in associative strength between dominant and subordinate reply-target pairs, $t(31) = -1.51$, $p = .14$, $\eta^2 = 0$.

Procedure. The procedure was identical to Experiment 1 (passive picture viewing), except that the stimulus timeline (see Table 1) was altered by the changes in the auditory stimuli. The onset of the first disambiguating word (e.g., “valuable” in the example above) occurred at 2710 ms, and its offset occurred at 3150 ms. All other significant time points were similar to Experiment 1, except that the offset of the reply occurred at 4830 ms, which was 100 ms later than in Experiment 1.

Results and Discussion

The overall results are shown in Figure 17. Compared to Exp. 1, the earlier biasing context did result in earlier meaning revision when the SRT was consistent with the context. However, meaning revision was only 500 ms faster than in Exp. 1 [4250 to 4500 ms: $F(1, 236) = .69$, *ns*; 4500 to 4750 ms: $F(1, 236) = 5.94$, $p < .05$], despite the fact that disambiguating information began 1600 ms earlier in the current experiment. Although a maintenance argument would predict that a shorter delay between the ambiguous word and the disambiguating context would generally be beneficial (Miyake et al., 1994), these results indicate that meaning revision can actually take comparatively longer if disambiguating information is introduced at an earlier point. If the subordinate meaning is activated more slowly, as the results of this study have typically shown, then it might be more difficult to revise the initial (dominant) interpretation when the disambiguating information is presented more quickly; the subordinate meaning would be weaker at earlier time points.

Twenty-six participants had a reading span score above the median (2.5). The fixation results for HS and LS are presented in Figures 18 and 19, respectively. No significant effects of span were observed.

Experiment 7: Prior Biasing Context

Experiment 6 showed that earlier subordinate-biased information can lead to earlier meaning revision, but another question is concerned with the possibility that biasing information that occurs prior to the ambiguous word could lead to reordered access (Duffy et al., 1988) or selective access (Swinney & Hakes, 1976). With respect to initial meaning activation, our results have supported the exhaustive access model (Swinney, 1979), but have also been consistent with other findings indicating that initial activation of the dominant meaning is stronger and occurs more rapidly than activation of the subordinate meaning (e.g., Simpson & Burgess, 1985). In order to evaluate differing hypotheses regarding the effects of context on initial meaning access, the current experiment involves biasing contextual information that precedes the ambiguous word (e.g., *"It was very valuable, but the diamond didn't come with rubies."* or *"It had nice dugouts, but the diamond didn't have any bleachers."*). It was predicted that the subordinate-biased context would result in reordered access: compared to the previous two-target experiments, initial activation of the subordinate meaning should be stronger and should precede or coincide with activation of the dominant meaning.

Method

Participants. Thirty-two members of the University of Missouri-Columbia community participated in exchange for eight to ten dollars or course credit. Participants met the same criteria as in previous experiments.

Materials. Sixty-four declarative sentences were constructed from the Experiment 6 question-reply pairs (e.g., *"Which diamond was very valuable?" "The one with the rubies."* became *"It was very valuable, but the diamond didn't come with rubies."*). See Appendix C for the sentence stimuli. Each sentence contained biasing information both prior to and subsequent to the ambiguous word.

To confirm that the prior biasing information was sufficiently biased toward the intended meaning, each sentence was truncated following the ambiguous word (e.g., *"It was very valuable, but the diamond…"*), and the meaning of each sentence was rated by 3 to 8 participants in a separate norming study based on a procedure used by Simpson (1981). Each participant rated either a dominant- or subordinate-biased sentence for each ambiguous word. Beneath each sentence, a scale consisting of 9 blanks appeared. The definition (or a synonym) of the dominant meaning appeared beneath the blank at one end of the scale, and the definition (or a synonym) of the subordinate meaning appeared beneath the blank at the opposite end (16 dominant-related and 16 subordinate-related definitions appeared on a given side of the booklet). Participants were asked to place a mark in the blank that corresponded to their estimation of the word's meaning as it was used in the truncated sentence. The center was designated as "neutral," and blanks between the center and the extremes were designated as intermediate levels of bias.

After the ratings were collected, each rating was assigned a numeric value corresponding to the selected blank, and an average bias estimate was calculated for each sentence. If the average bias estimate for an individual sentence was less than 1 on a scale of 0 to 4, then the sentence was revised and rated again. The final average bias estimates were 3.61 for the dominant-biased sentences and 3.00 for the subordinate-biased sentences.

Relationships between each disambiguating word and the corresponding target were obtained from the Nelson et al. (1998) word association norms, or were estimated using ratings made by 28 undergraduate students, who participated in exchange for course credit. For the first disambiguating word (e.g., "valuable" and "dugouts"), associations between disambiguating words and related targets were weak (dominant: *M* = 4.06%, *SD* = 17.9%; subordinate: *M* = 6.99%, *SD* = 17.04%), and there was no significant difference in associative strength between dominant and subordinate context-target pairs, $t(24) = -.40$, $p = .70$, $\eta^2 = 0$ (seven reply-target associations were unknown). For the second disambiguating word (e.g., “rubies” and “bleachers”), associations between disambiguating words and related targets were again weak (dominant: *M* = 3.87%, *SD* = 17.93%; subordinate: *M* = 3.91%, *SD* = 18.22%), and there was no significant difference in associative strength between dominant and subordinate context-target pairs, $t(27) = -.01$, $p = 1$, $\eta^2 = 0$ (four reply-target associations were unknown).

Procedure. The procedure was identical to Experiment 1 (passive picture viewing). The stimulus timeline is presented in Table 1.

Results and Discussion

Figure 20 depicts the overall fixation results. Following the prior biasing information (which occurred between 2230 and 2730 ms), participants rapidly fixated the contextually-consistent target at an above-baseline rate between 2750 ms and 3000 ms [dominant: $F(1, 124) = 7.54$, $p < .01$; subordinate: $F(1, 124) = 11.68$, $p < .001$]. Participants continued to fixate the consistent related target between the onset of the ambiguous word (3000 ms) and the onset of the second disambiguating context word [3750 ms; dominant: $F(1, 124) = 61.32$, $p < .001$; subordinate: $F(1, 124) = 44.7$, $p < .001$]. Furthermore, the consistent target was also fixated between the onset of the second disambiguating context word and the offset of the pictures [7000 ms; dominant: $F(1, 124) = 67.5$, $p < .001$; subordinate: $F(1, 124) = 22.2$, $p <.001$].

Although the consistent meaning was selected regardless of meaning frequency, meaning frequency did have an effect on the likelihood that the inconsistent target would be fixated. Following the ambiguous word, fixation of the inconsistent DRT increased above baseline; in contrast, fixation of the inconsistent SRT continued to overlap with the baseline, as can be seen in Figure 20. Thus, reordered access (Duffy et al., 1988) was observed: selective access occurred when the context was biased toward the dominant meaning, but exhaustive access occurred when context was biased toward the subordinate meaning (see also Huettig & Altmann, 2004; Tabossi, 1988; Tabossi, Colombo, & Job, 1987).

Similarly to Experiments 1 and 3, participants' awareness and strategy use had an effect on the pattern of results; 18 participants met the criteria. Figures 21 and 22 depict the results for AI and UU participants, respectively. The interaction between awareness and the pattern of fixations was significant between the onset of the ambiguous word and the offset of the pictures [3000 to 3750 ms: $F(4, 120) = 2.55$, $p < .05$; 3750 ms to 7000 ms: $F(4, 120) = 6.48$, $p < .01$]. AI participants demonstrated fixations that were consistent with the overall pattern of results, whereas UU participants fixated inconsistent and consistent targets at a similar rate following the ambiguous word. These results suggest that the use of controlled attention may be necessary to suppress or inhibit the inappropriate meaning (Neely, 1977; Simpson & Burgess, 1985).

Fifteen participants had reading span scores above the median of 2.5, but no effects of span were significant. HS were not more likely to meet the aware/intentional criteria, $\chi^2(1, N = 32) = 0.6$, $p = .44$.

General Discussion

This study has had two parallel purposes: to examine the variables that influence the time course of ambiguity resolution, and to investigate methodological issues associated with the visual world paradigm. With respect to the first purpose, the results have provided evidence of the effects of meaning frequency and biasing context, as well as their interaction. The dominant meaning was typically activated strongly and rapidly, while subordinate meaning activation was typically slower and weaker (Simpson & Burgess, 1985; cf. Seidenberg et al., 1982). Following initial selection of the dominant meaning, subsequent disambiguating context typically had a rapid effect, resulting in meaning revision if the context was consistent with the subordinate meaning, while the dominant meaning remained active if it was supported by the context. However, biasing context interacted with meaning frequency in other circumstances. Most strikingly, when biasing context preceded the ambiguous word, only the dominant meaning was activated in a dominant-biased context, whereas both meanings were activated in the subordinate-biased context (Duffy et al., 1988). Thus, whereas lexical access in a neutral context is exhaustive (although subordinate meaning activation is slower and weaker), lexical access in a biasing context can be selective or exhaustive, depending on the frequency of the biased meaning.

The results of this study have failed to provide support for the role of syntactic/thematic integration (Peterson & Savoy, 1994). Although the stimuli used were very similar to those utilized by Peterson and Savoy, a different pattern of results was observed through the use of eye tracking and the visual world paradigm, as opposed to cross-modal priming effects in a speeded naming task. Multiple meanings were not maintained until dominant meaning selection occurred following the processing of the sentence-final verb; instead, the dominant meaning was typically selected prior to the offset of the sentence, and subordinate meaning activation occurred more slowly. An exception to this pattern occurred with the one-target visual context used in Exp. 5: the two meanings were activated at the same time. However, clear selection of the dominant meaning was not apparent following the sentence-final verb. Instead, both meanings remained active well above baseline, although dominant meaning activation was stronger. In contrast, Peterson and Savoy found that the subordinate meaning was no longer active by 300 ms after the offset of the verb. The discrepancy between the findings of this study and those of Peterson and Savoy are likely due to methodological issues associated with the cross-modal priming procedure. In this procedure, targets must be presented at a specific time point; because of this, it is difficult to examine the pattern of meaning activation over time.

With respect to the effects of working memory capacity on ambiguity resolution, the results of this study have not provided evidence for the maintenance hypothesis of Miyake et al. (1994). Rather than maintaining multiple meanings over time, HS typically demonstrated strong activation of the dominant meaning and subordinate-meaning activation that was initially weak; LS demonstrated the same pattern. However, it is possible that the span results of the current study are not comparable to the results of Miyake et al., whose HS participants had a higher span than those classified as HS in the current study. Although span did not have significant effects on fixations in the current study, an interesting trend was observed in Experiment 6: for HS, fixation of the inconsistent DRT decreased more quickly, allowing more rapid meaning revision. Thus, rather than maintaining multiple meanings over time, HS may be able to suppress the inconsistent dominant meaning more efficiently, enabling them to revise their initial interpretation more quickly (Gernsbacher et al., 1990; Gunter et al., 2003).

The mechanism of suppression is associated with attention and controlled processing (Neely, 1977). The effects of awareness and strategy use observed in the current study provide evidence that attention and controlled processing influence ambiguity resolution. In the three passive-viewing experiments in which these effects were examined, UU participants were less likely to fixate related targets, were less likely to activate the subordinate meaning, and were less likely to show strong selection of the contextually-consistent meaning. However, it is not the case that participants must be aware of the presence of related targets or that they must intentionally fixate them in order for meaning activation to be observed in the visual world paradigm. For example, although fixation rates for UU participants were lower than those for AI participants in Exp. 1, UU participants nonetheless demonstrated initial activation of the dominant meaning and selection of the contextually-consistent subordinate meaning. Thus, it appears that awareness and strategy use enhance unconscious meaning activation and selection processes. HS were more likely to meet the aware/intentional criteria in one experiment (Exp. 3), in which the general level of awareness and strategy use was low. These findings suggest that HS are more likely to utilize controlled attention in situations that would not be expected to elicit its use.

Using an active task involving explicit instructions might be a way to eliminate the effects of awareness and strategy use within the visual world paradigm. However, explicit instructions can also influence the time course of ambiguity resolution. For example, utilizing explicit instructions to fixate the most strongly related target causes inhibition of the contextually-inconsistent dominant meaning to occur more slowly. A different approach to reducing awareness and strategy use might be to use words as the visual stimuli, rather than pictures. The results of Experiment 3 indicate that this approach could be an effective way to reduce awareness and strategy use. Nevertheless, this type of procedure also influences the time course of ambiguity resolution.

Although visual words elicited a different pattern of fixations compared to pictures, even when explicit instructions were utilized, this does not mean that visual words cannot be used effectively as stimuli in the visual world paradigm. When participants are asked to predict the final word of rhyming verse, they are able to rapidly fixate the correct word at a time point that corresponds with cloze probabilities obtained offline (e.g., compared to a rhyming competitor, the correct word is fixated more quickly in a more constraining context; Woehrle & King, 2005). Thus, the semantic context can have a powerful effect on fixation probabilities for visual words.

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APPENDICES

Appendix A

Critical Sentences from Experiments 1 through 5

Question	Reply
Which ball did the woman miss?	D: The one at the net. S: The one at the mansion.
Which hand did the man examine?	D: The one with the scars. S: The one with the kings.
Which mint did the girl see?	D: The one in the saucer. S: The one in the capital.
Which horn did the man buy?	D: The one with the mouthpiece. S: The one with the carving.
Which toast did the woman make?	D: The one with the jelly. S: The one with the vodka.
Which bank did the man visit?	D: The one across the street. S: The one across the river.
Which letter did the man write?	D: The one in the newspaper. S: The one in the manuscript.
Which diamond did the man like?	D: The one with the rubies. S: The one with the bleachers.
Which bark did the woman dislike?	D: The one from the backyard. S: The one from the sycamore.
Which ruler did the girl prefer?	D: The one from the bookstore. S: The one from the kingdom.
Which key did the man adjust?	D: The one for the handcuffs. S: The one on the folksong.
Which pen did the boy use?	D: The one with the cap. S: The one with the goat.

Which court did the woman leave?	D: The one in the city. S: The one in the park.
Which calf did the girl see?	D: The one in the stall. S: The one in the cast.
Which vault did the man prefer?	D: The one in the library. S: The one in the Olympics.
Which file did the woman need?	D: The one near the keyboard. S: The one near the polish.
Which fan did the man like?	D: The one with the battery. S: The one with the sweatshirt.
Which stage did the man exit?	D: The one at the theater. S: The one at the barbershop.
Which game did the boy watch?	D: The one on the table. S: The one on the trail.
Which plant did the woman approach?	D: The one outside of the house. S: The one outside of the town.
Which log did the woman move?	D: The one in the forest. S: The one in the office.
Which shell did the man inspect?	D: The one on the beach. S: The one on the tank.
Which fold did the girl observe?	D: The one in the cloth. S: The one in the field.
Which figure did the boy erase?	D: The one from the drawing. S: The one from the equation.
Which ear did the man touch?	D: The one on the body. S: The one on the stalk.
Which bug did the woman destroy?	D: The one in the kitchen. S: The one in the telephone.
Which star did the girl admire?	D: The one in the East. S: The one in the show.

Which dive did the man dislike?	D: The one with the backflip. S: The one with the roaches.
Which perch did the woman dislike?	D: The one in the cage. S: The one in the lake.
Which runner did the man push?	D: The one on the track. S: The one on the floor.
Which drill did the boy watch?	D: The one at the shop. S: The one at the base.
Which staple did the girl misplace?	D: The one in the desk. S: The one in the cupboard.

Appendix B

Critical Sentences from Experiment 6

Question	Reply
D: Which horn was difficult to play?	The one with the mouthpiece.
S: Which horn was difficult to carve?	The one with the powder.
D: Which vault was hard to open?	The one in the library.
S: Which vault was hard to attempt?	The one in the Olympics.
D: Which court was full of reporters?	The one in the city.
S: Which court was full of spectators?	The one in the park.
D: Which drill was placed in the box?	The one at the shop.
S: Which drill was placed in the routine?	The one at the base.
D: Which runner was removed from the race?	The one on the bus.
S: Which runner was removed from the store?	The one on the truck.
D: Which fan wouldn’t stop spinning?	The one with the battery.
S: Which fan wouldn’t stop yelling?	The one with the sweatshirt.
D: Which star disappeared in the summer?	The one in the constellation.
S: Which star disappeared into the car?	The one in the production.
D: Which ball went past the player?	The one at the net.
S: Which ball went past midnight?	The one at the mansion.
D: Which letter appeared in the newspaper?	The one from the politician.
S: Which letter appeared in the manuscript?	The one from the language.
D: Which key wasn’t easy to turn?	The one for the handcuffs.
S: Which key wasn’t easy to play?	The one for the folksong.
D: Which game ran on for hours?	The one on the table.
S: Which game ran on the trail?	The one in the woods.
D: Which figure appeared in the drawing?	The one from the painting.
S: Which figure appeared in the problem?	The one from the equation.
D: Which perch was good to sit on?	The one in the cage.
S: Which perch was good to eat?	The one from the lake.

D: Which calf was the last to be born?	The one in the stall.
S: Which calf was the last to be pulled?	The one in the bandage.
D: Which log was moved off of the field?	The one in the forest.
S: Which log was moved off of the desk?	The one in the office.
D: Which ear was placed on the toy?	The one from the doll.
S: Which ear was placed on the plate?	The one from the stalk.
D: Which hand wasn't badly injured?	The one with the scars.
S: Which hand wasn't badly played?	The one with the queen.
D: Which plant was moved to the yard?	The one next to the fence.
S: Which plant was moved to Michigan?	The one next to the town.
D: Which ruler was hard to read?	The one from the bookstore.
S: Which ruler was hard to please?	The one from the kingdom.
D: Which bank had a nice lobby?	The one across the street.
S: Which bank had a nice footpath?	The one across the river.
D: Which toast was very burnt?	The one with the jelly.
S: Which toast was very amusing?	The one with the vodka.
D: Which mint was taken out of the box?	The one in the saucer.
S: Which mint was taken out of the state?	The one in the capital.
D: Which bug was difficult to catch?	The one in the basement.
S: Which bug was difficult to wire?	The one in the telephone.
D: Which bark went on for hours?	The one from the backyard.
S: Which bark went on the fire?	The one from the sycamore.
D: Which file was very boring?	The one near the keyboard.
S: Which file was very sharp?	The one near the polish.
D: Which pen was always leaking?	The one without the cap.
S: Which pen was always clean?	The one without the goat.
D: Which diamond was very valuable?	The one with the rubies.
S: Which diamond was very overgrown?	The one with the bleachers.
D: Which dive was extremely risky?	The one with the backflip.
S: Which dive was extremely filthy?	The one with the roaches.

D: Which shell was returned to the water?	The one from the beach.
S: Which shell was returned to the chamber?	The one from the tank.
D: Which fold was very wrinkled?	The one in the cloth.
S: Which fold was very scattered?	The one in the field.
D: Which stage was under the lights?	The one at the theater.
S: Which stage was extremely slow?	The one at the barbershop.
D: Which staple fell off of the desk?	The one from the document.
S: Which staple fell out of the cupboard?	The one in the kitchen.

Appendix C

Critical Sentences from Experiment 7

D: Being out of tune, the horn was difficult to play.
S: Being very pointed, the horn was difficult to carve.

D: Because it was almost full, the vault was hard to close.
S: Because it was very high, the vault was hard to attempt.

D: Since it was an important case, the court was full of reporters.
S: Since it was an important match, the court was full of spectators.

D: It was getting late at the oil rig, so the drill was deactivated until tomorrow.
S: It was getting late at the base, so the drill was postponed until tomorrow.

D: He was very exhausted, so the runner was removed from the race.
S: It was very frayed, so the runner was removed from the store.

D: It had an old battery, but the fan was still spinning.
S: He was told to sit down, but the fan was still yelling.

D: At other times it was bright, but the star disappeared during the summer.
S: She usually sought publicity, but the star disappeared into the limousine.

D: Over by the net, the ball went past the player.
S: Inside the mansion, the ball went past midnight.

D: After being approved by the editor, the letter appeared in the newspaper.
S: After being changed to a new symbol, the letter appeared in the alphabet.

D: Since they were damaged handcuffs, the key wasn't easy to turn.
S: Since she had a damaged instrument, the key wasn't easy to play.

D: In the back of the casino, the game ran on for hours.
S: Near the back of the clearing, the game ran on the trail.

D: Just like the painting, the figure appeared in the drawing.
S: Just like the equation, the figure appeared in the problem.

D: After being placed in the birdcage, the perch was good to sit on.
S: After being removed from the lake, the perch was good to eat.

D: Inside the last stall, the calf had been born recently.
S: Inside the heavy cast, the calf had been injured recently.

D: Currently in the forest, the log had been moved from the field.
S: Currently in the office, the log had been moved from the desk.

D: Removed from the doll, the ear was placed on the toy.
S: Removed from the stalk, the ear was placed in the pot.

D: Because of the glove, the hand wasn't badly injured.
S: Because of the ace, the hand wasn't badly played.

D: Originally near the sunlight, the plant was moved into the yard.
S: Originally near the refinery, the plant was moved into the city.

D: It was difficult to read, but the ruler was hard to break.
S: He was respected, but the ruler was hard to please.

D: It was an old building, but the bank had a nice lobby.
S: It was a little muddy, but the bank had a nice footpath.

D: It was good jelly, and the toast was very tasty.
S: It was good vodka, and the toast was very amusing.

D: Previously in the box, the mint was moved to the saucer.
S: Previously out of state, the mint was moved to the capital.

D: Deep within the basement, the bug was difficult to catch.
S: Deep within the telephone, the bug was difficult to wire.

D: Coming from the backyard, the bark went on for hours.
S: Coming from the sycamore, the bark went on the fire.

D: Lying near the keyboard, the file was very thick.
S: Lying near the polish, the file was very sharp.

D: Since it didn't have a cap, the pen was always leaking.
S: Since it didn't contain a goat, the pen was always clean.

D: It was very valuable, but the diamond didn't come with rubies.
S: It had nice dugouts, but the diamond didn't have any bleachers.

D: With the difficult backflip, the dive was extremely risky.
S: With the numerous roaches, the dive was extremely filthy.

D: Over by the beach, the shell was returned to the water.
S: Over by the missile, the shell was returned to the chamber.

D: By the edge of the large cloth, the fold was very wrinkled.
S: By the edge of the large field, the fold was very rundown.

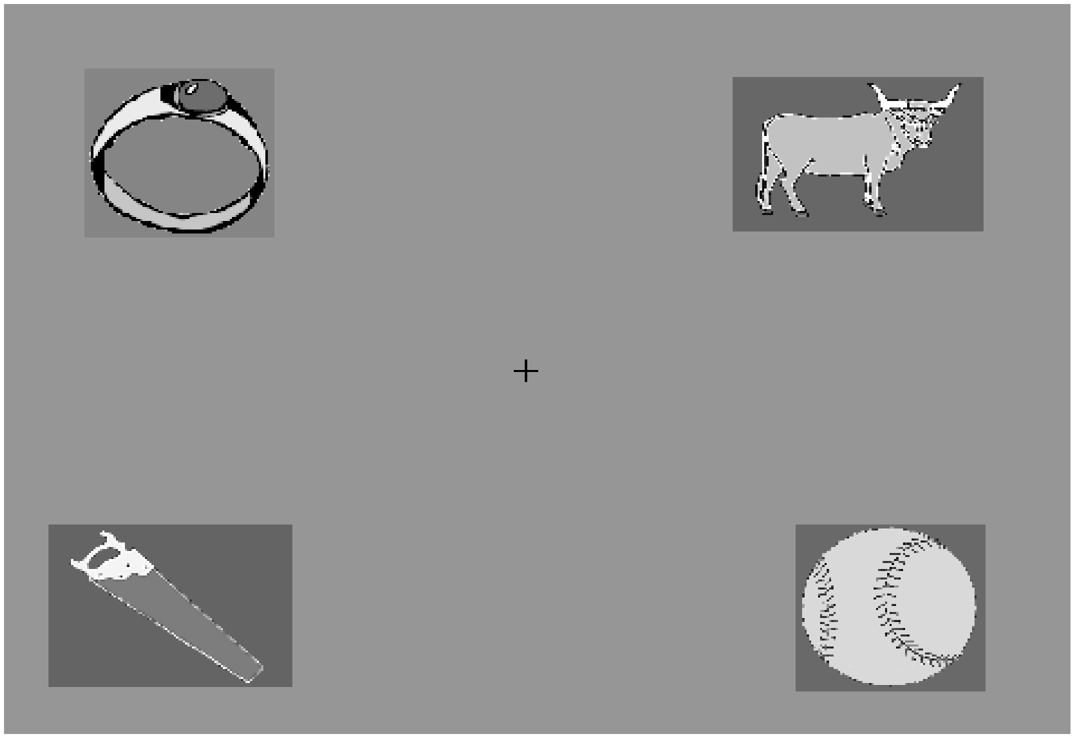
D: In the crowded theater, the stage was under the lights.
S: In the crowded road, the stage was extremely slow.

D: Inside of the desk, the staple was on the document.
S: Inside of the kitchen, the staple was in the cupboard.

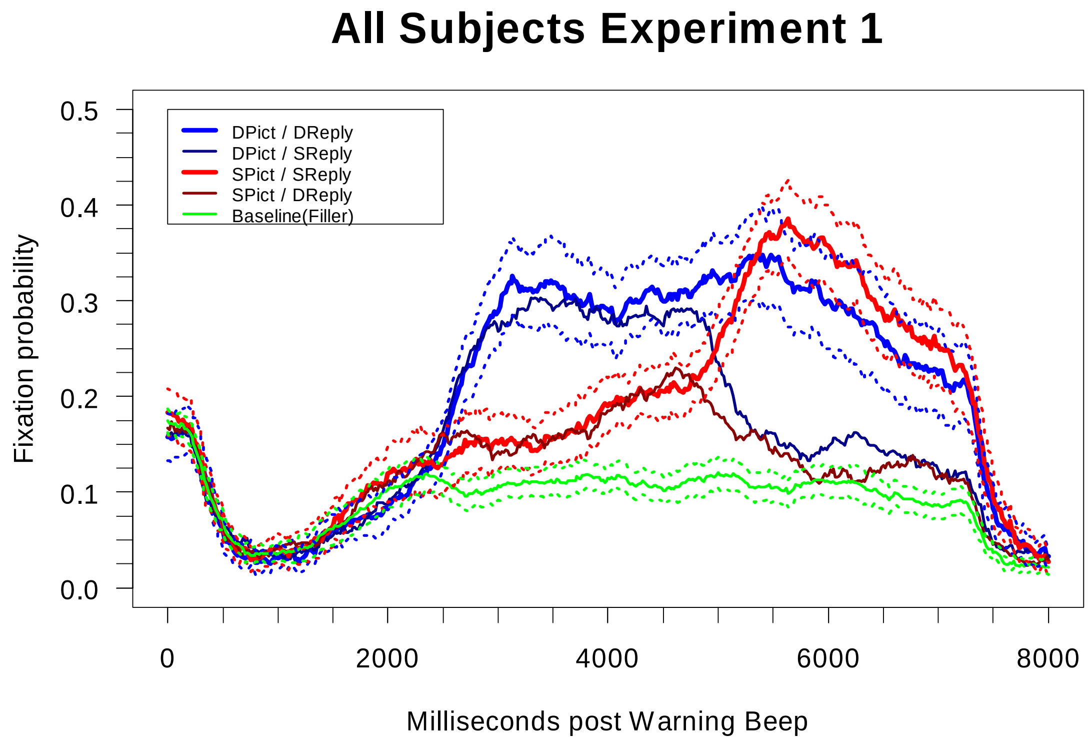
Table 1

Stimulus Timelines

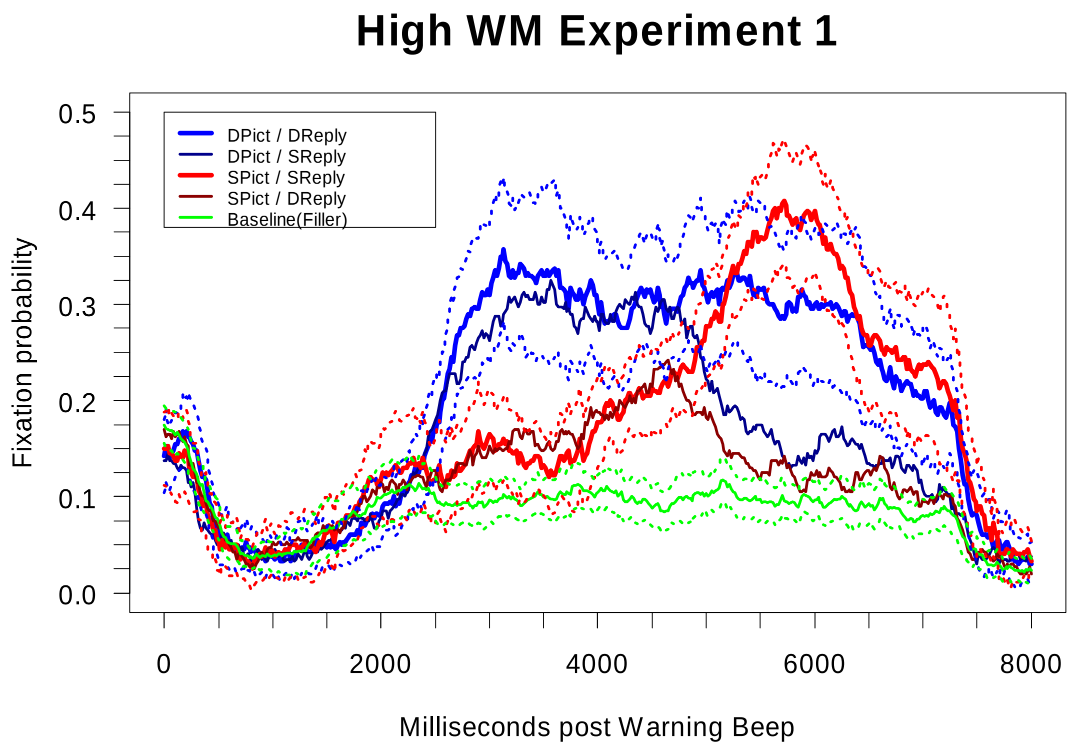
	Stimulus Set		
	Biasing Reply (Experiments 1-5)	Biasing Question and Reply (Exp. 6)	Prior and Subsequent Bias (Experiment 7)
- 3000 ms	pictures appear	pictures appear	pictures appear
0 ms	warning tone	warning tone	warning tone
1500 ms	question onset	question onset	sentence onset
~1750 ms	ambig. word onset	ambig. word onset	
~2000 ms	ambig. word offset	ambig. word offset	
~2250 ms			1st bias onset
~2500 ms			
~2750 ms		1st bias onset	1st bias offset
~3000 ms	question offset		ambig. word onset
~3250 ms		1st bias/question offset	ambig. word offset
~3500 ms			
~3750 ms	reply onset	reply onset	2nd bias onset
~4000 ms			
~4250 ms	bias onset	2nd bias onset	2nd bias/sentence offset
~4500 ms			
~4750 ms	bias/reply offset	2nd bias/reply offset	
7000 ms	pictures end	pictures end	pictures end

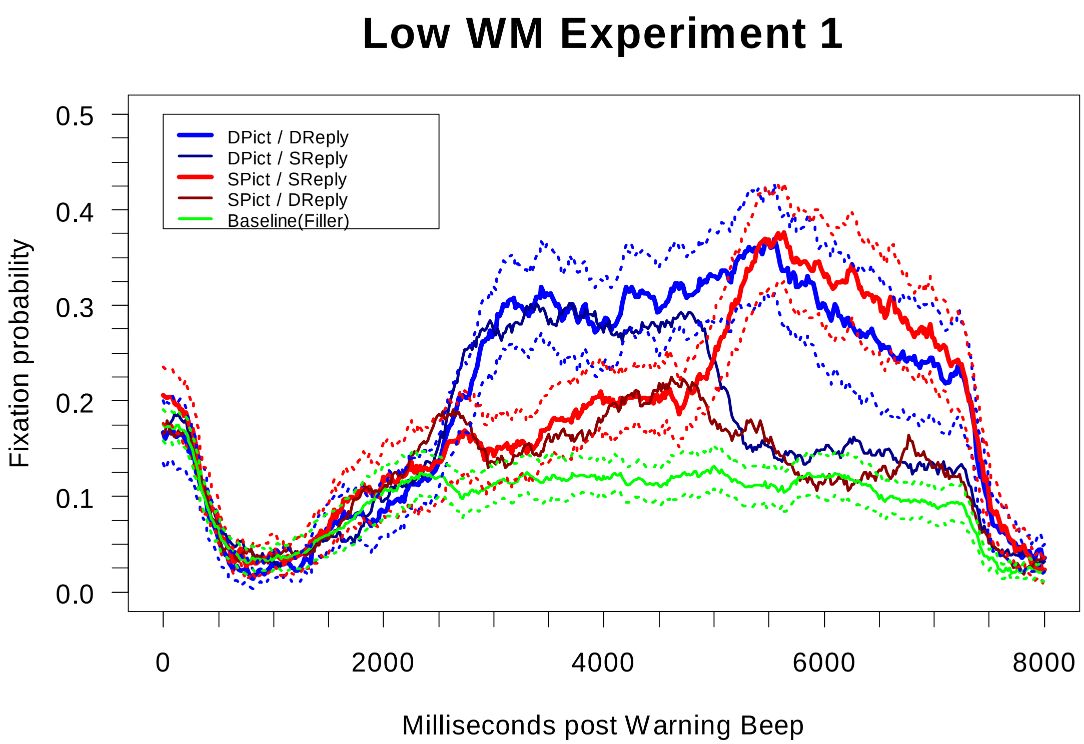


Note. Example picture stimuli from the “diamond” trial The picture of the ring is the dominant-related target, the picture of the baseball is the subordinate-related target, and the other two pictures are unrelated images from other critical trials.

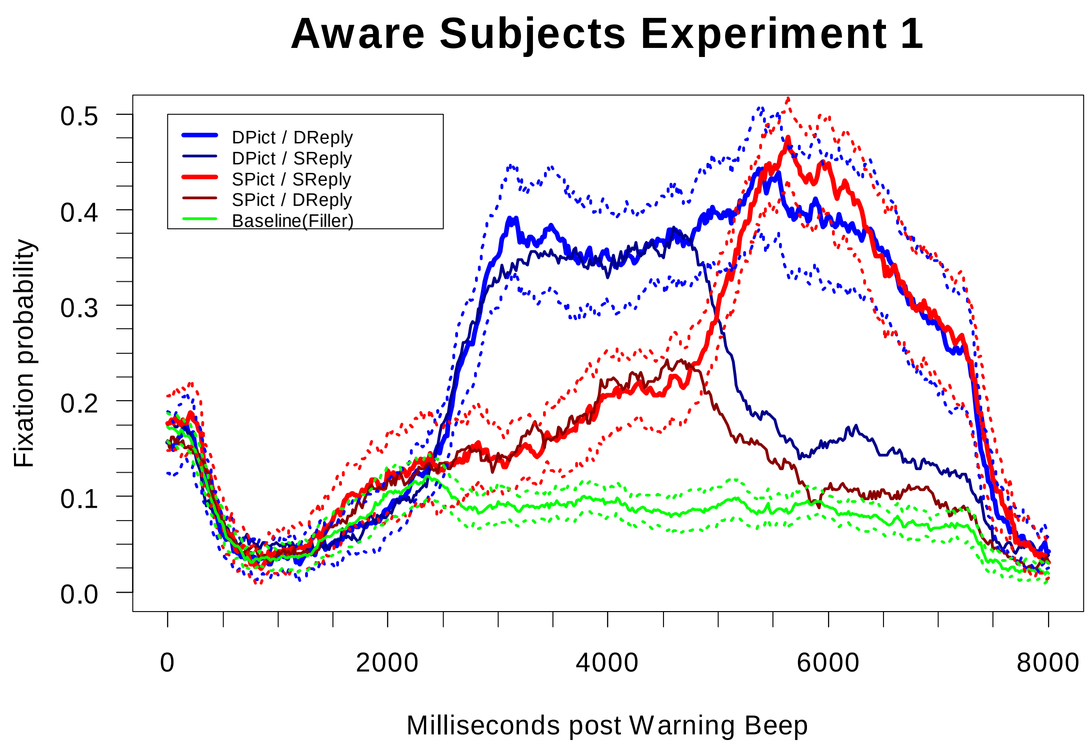


Note. For this figure and those that follow, each thick line represents the probability of fixating the dominant- or subordinate-related target in the appropriate context, while each thin line represents the probability of fixating a related target in the incorrect context (note that the context is not "incorrect" until the onset of the disambiguating information). Dotted lines are 95% confidence intervals for each type of correct fixation and the baseline (average fixation of the two unrelated filler pictures).

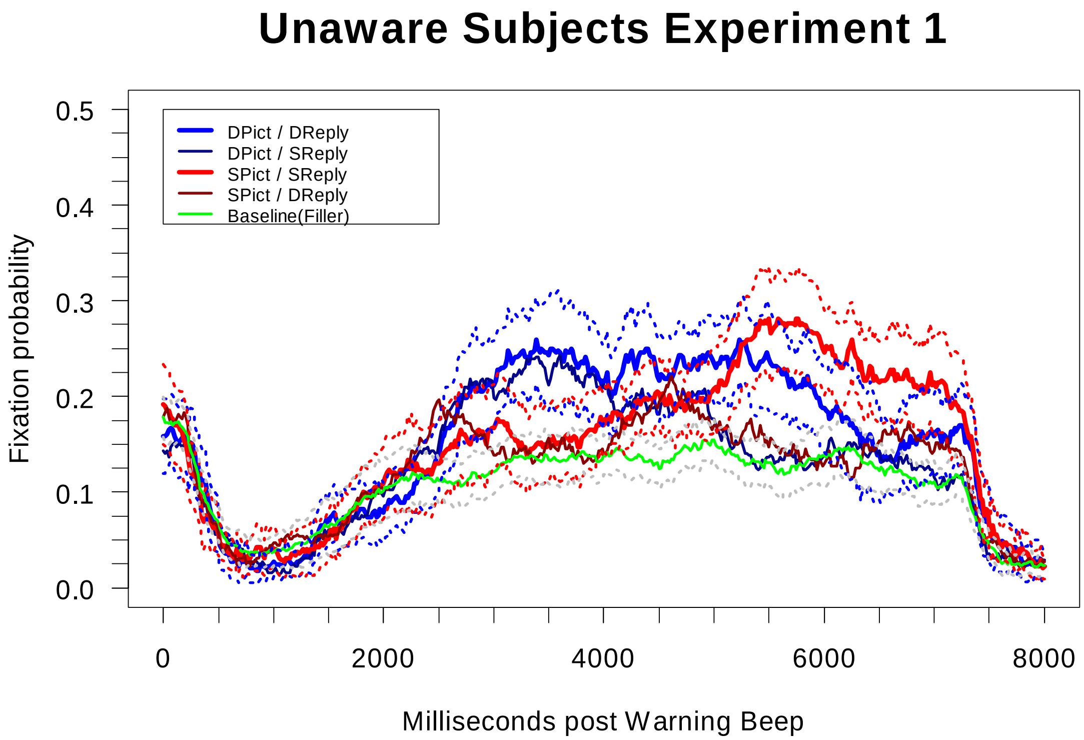

High WM Experiment 1
DPict / DReply
DPict / SReply
SPict / SReply
SPict / DReply
Baseline(Filler)
Fixation probability
0.5
0.4
0.3
0.2
0.1
0.0
0
2000
4000
6000
8000
Milliseconds post Warning Beep

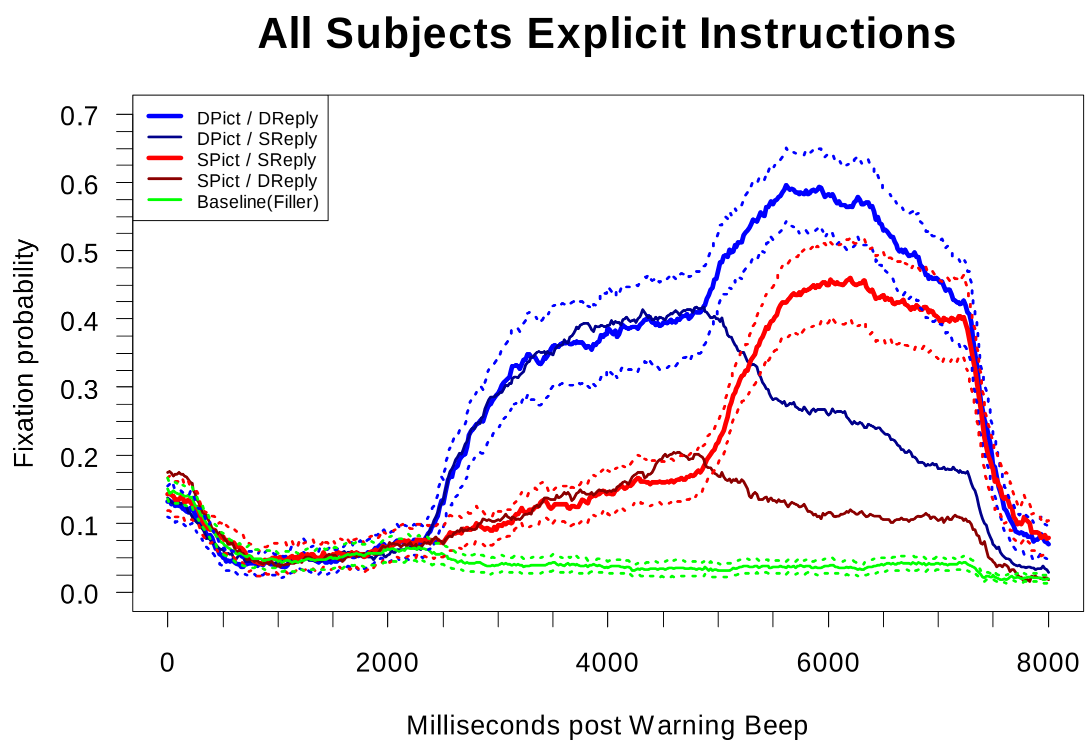


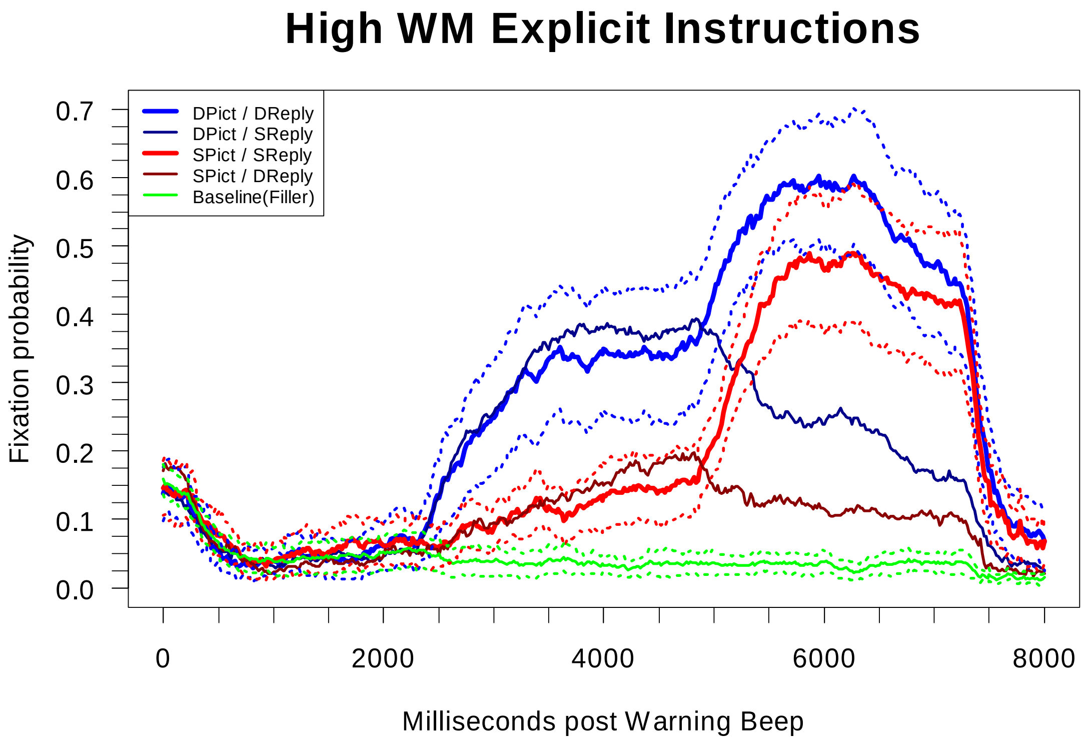
Low WM Experiment 1
Fixation probability
0.5
0.4
0.3
0.2
0.1
0.0
DPict / DReply
DPict / SReply
SPict / SReply
SPict / DReply
Baseline(Filler)
0
2000
4000
6000
8000
Milliseconds post Warning Beep

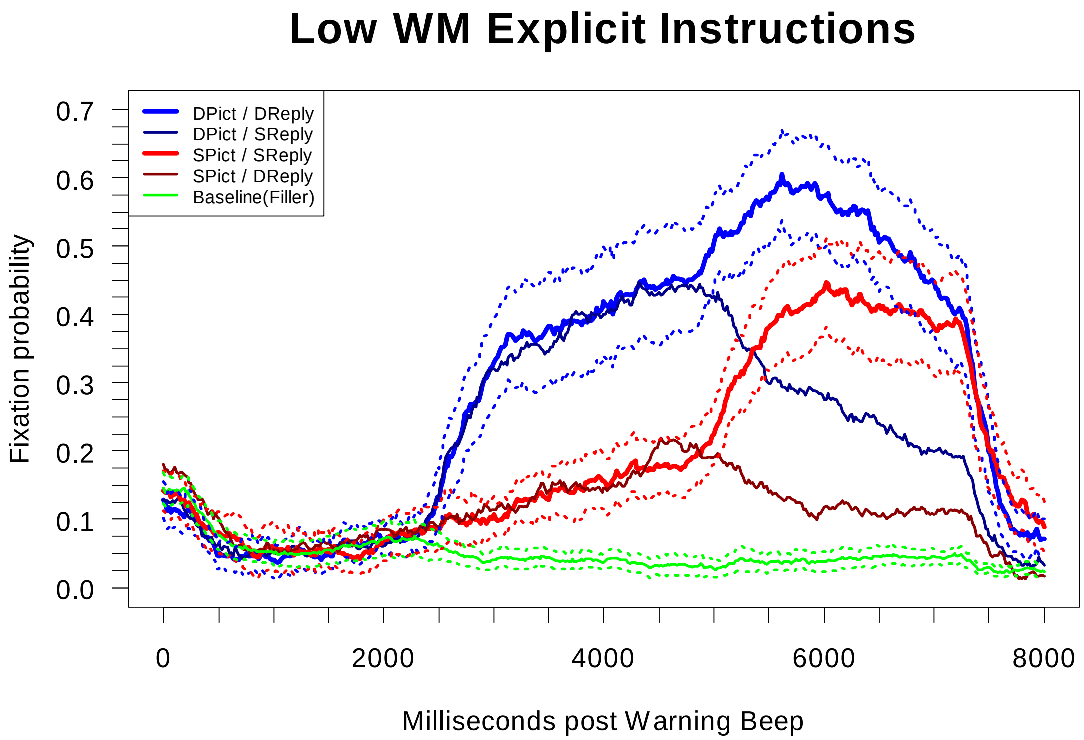


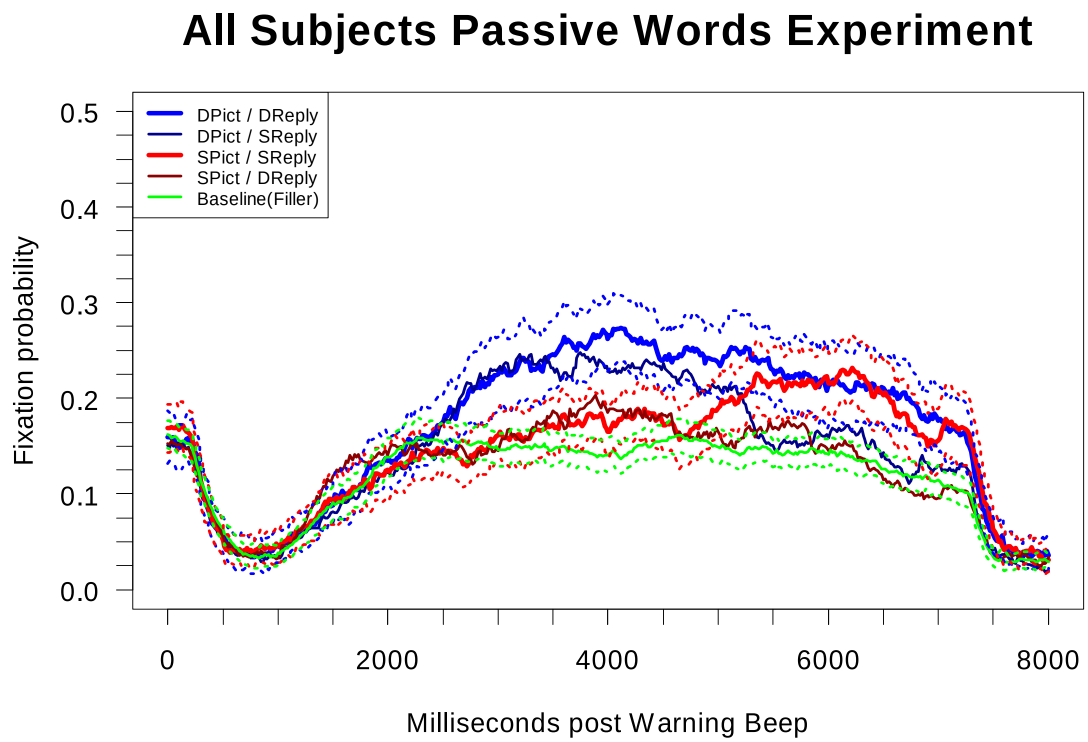
Aware Subjects Experiment 1
DPict / DReply
DPict / SReply
SPict / SReply
SPict / DReply
Baseline(Filler)
Fixation probability
0.0
0.1
0.2
0.3
0.4
0.5
0
2000
4000
6000
8000
Milliseconds post Warning Beep

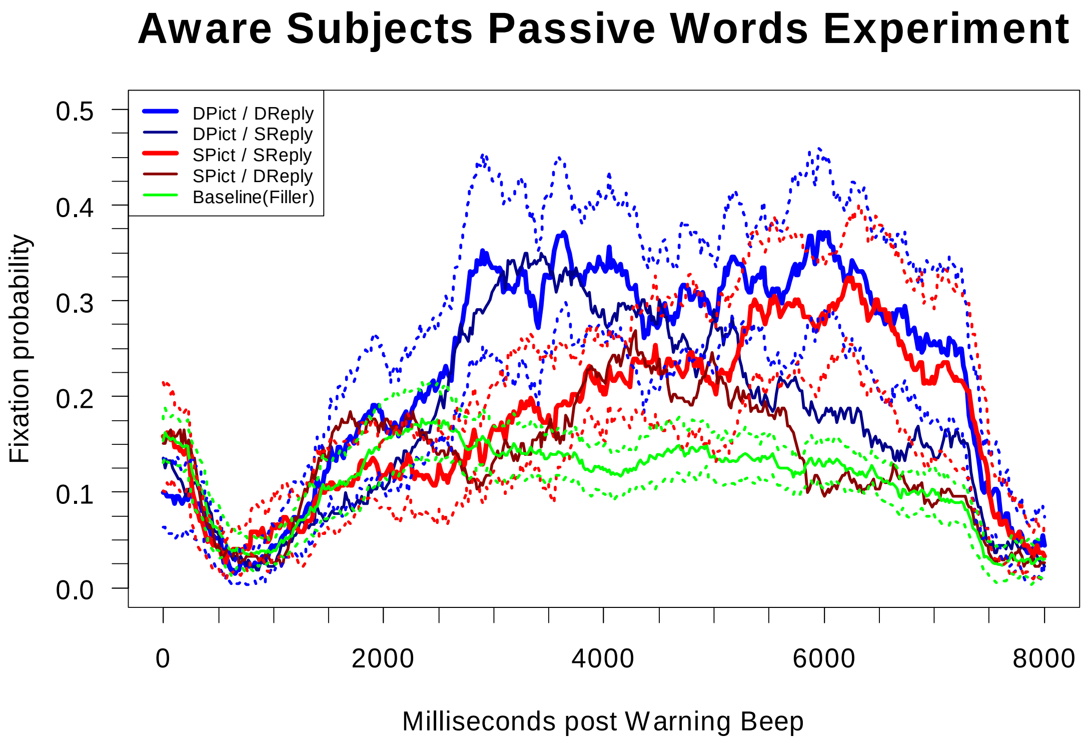

Unaware Subjects Experiment 1
DPict / DReply
DPict / SReply
SPict / SReply
SPict / DReply
Baseline(Filler)
Fixation probability
0.5
0.4
0.3
0.2
0.1
0.0
0
2000
4000
6000
8000
Milliseconds post Warning Beep

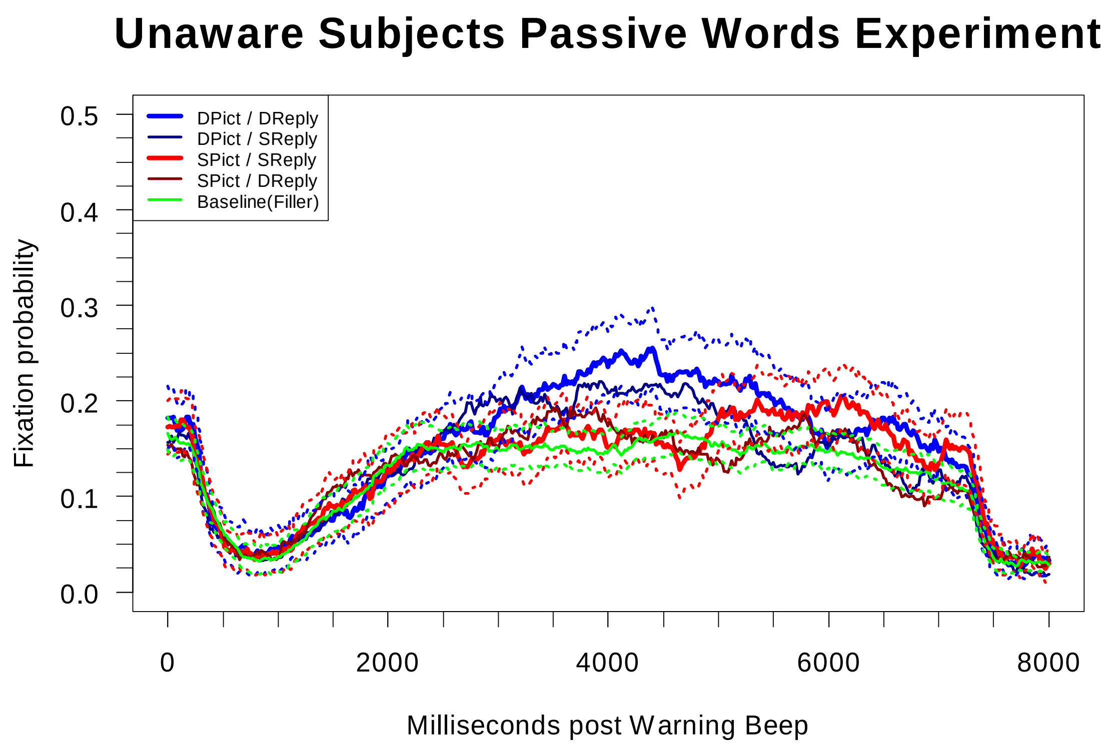

All Subjects Explicit Instructions
DPict / DReply
DPict / SReply
SPict / SReply
SPict / DReply
Baseline(Filler)
Fixation probability
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
2000
4000
6000
8000
Milliseconds post Warning Beep

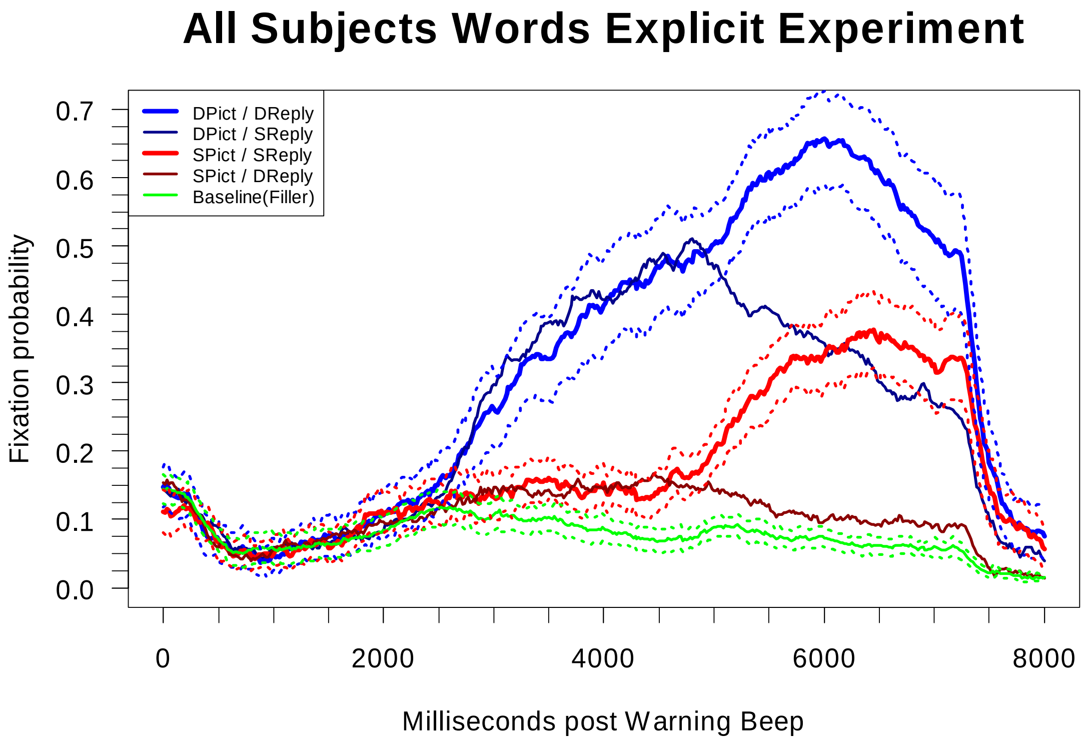

High WM Explicit Instructions
DPict / DReply
DPict / SReply
SPict / SReply
SPict / DReply
Baseline(Filler)
Fixation probability
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
2000
4000
6000
8000
Milliseconds post Warning Beep

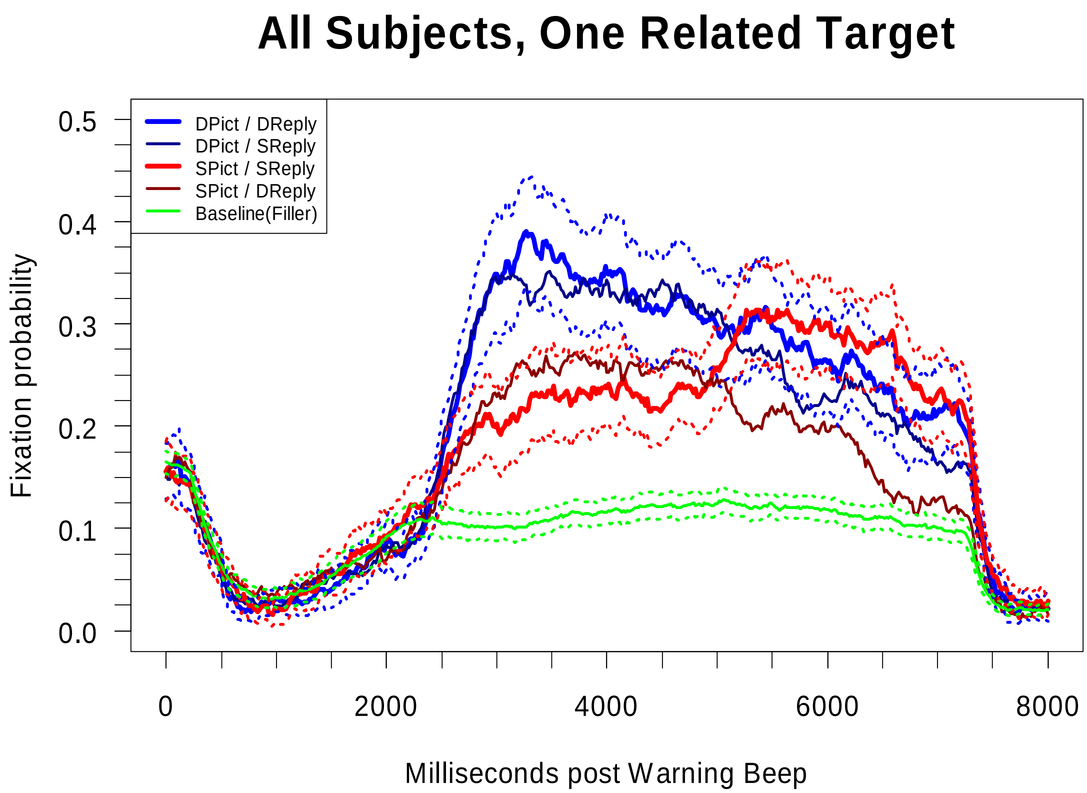

Low WM Explicit Instructions
DPict / DReply
DPict / SReply
SPict / SReply
SPict / DReply
Baseline(Filler)
Fixation probability
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0
2000
4000
6000
8000
Milliseconds post Warning Beep

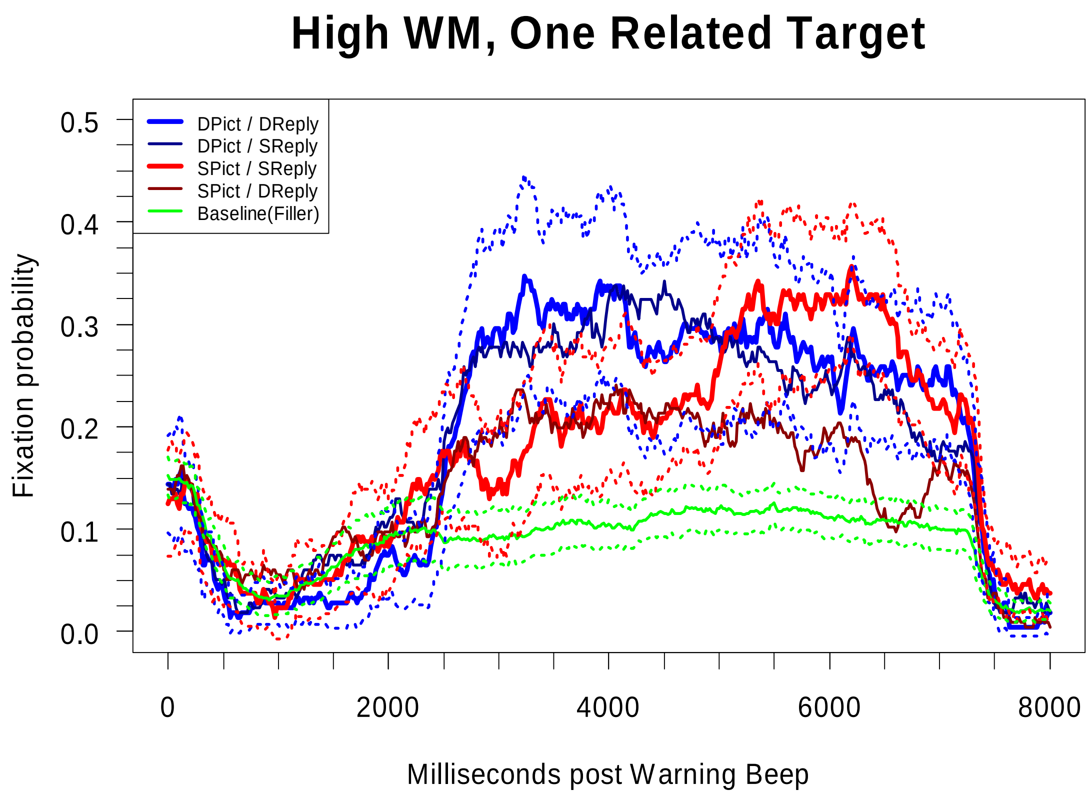

All Subjects Passive Words Experiment
DPict / DReply
DPict / SReply
SPict / SReply
SPict / DReply
Baseline(Filler)
Fixation probability
0.5
0.4
0.3
0.2
0.1
0.0
0
2000
4000
6000
8000
Milliseconds post Warning Beep

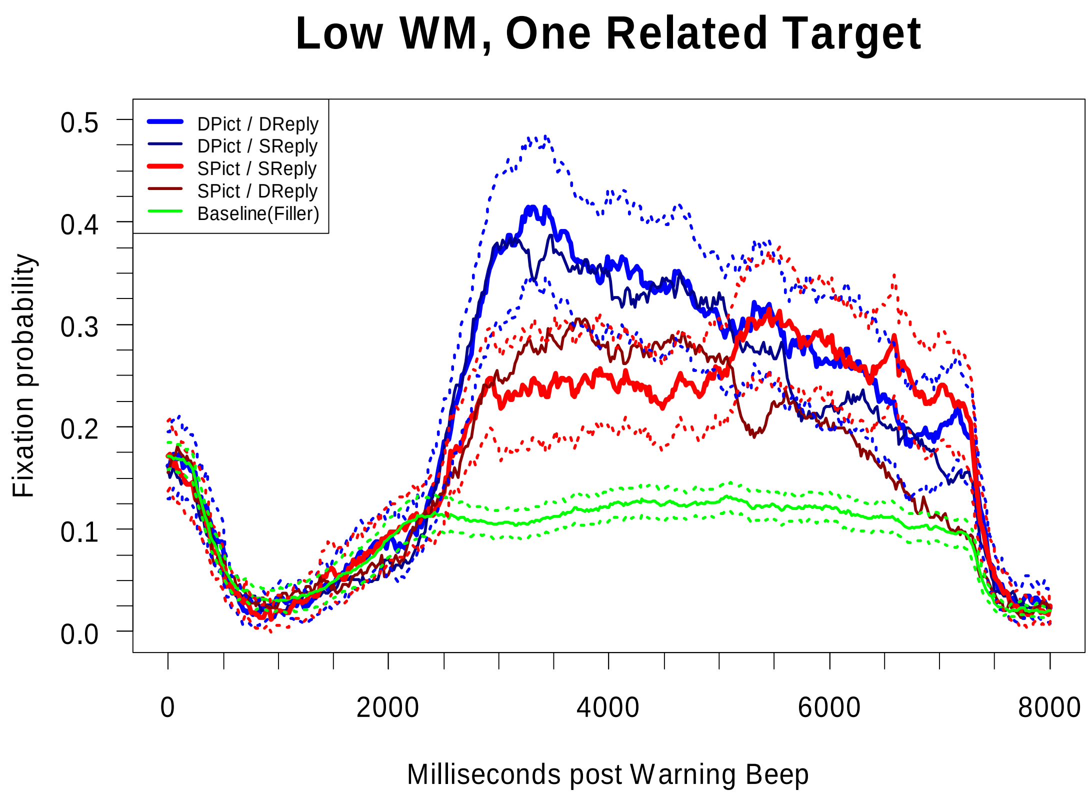

Aware Subjects Passive Words Experiment
DPict / DReply
DPict / SReply
SPict / SReply
SPict / DReply
Baseline(Filler)
Fixation probability
0.0
0.1
0.2
0.3
0.4
0.5
0
2000
4000
6000
8000
Milliseconds post Warning Beep


Unaware Subjects Passive Words Experiment
DPict / DReply
DPict / SReply
SPict / SReply
SPict / DReply
Baseline(Filler)
Fixation probability
0.0
0.1
0.2
0.3
0.4
0.5
0
2000
4000
6000
8000
Milliseconds post Warning Beep

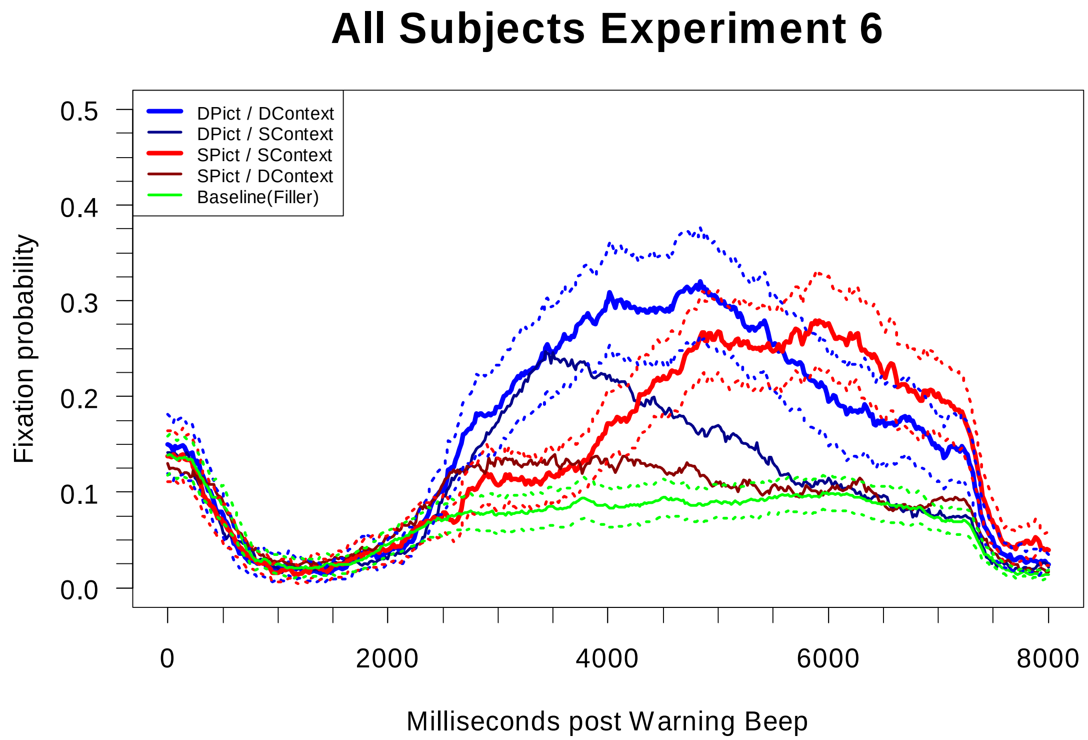

All Subjects Words Explicit Experiment
DPict / DReply
DPict / SReply
SPict / SReply
SPict / DReply
Baseline(Filler)
Fixation probability
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0
2000
4000
6000
8000
Milliseconds post Warning Beep

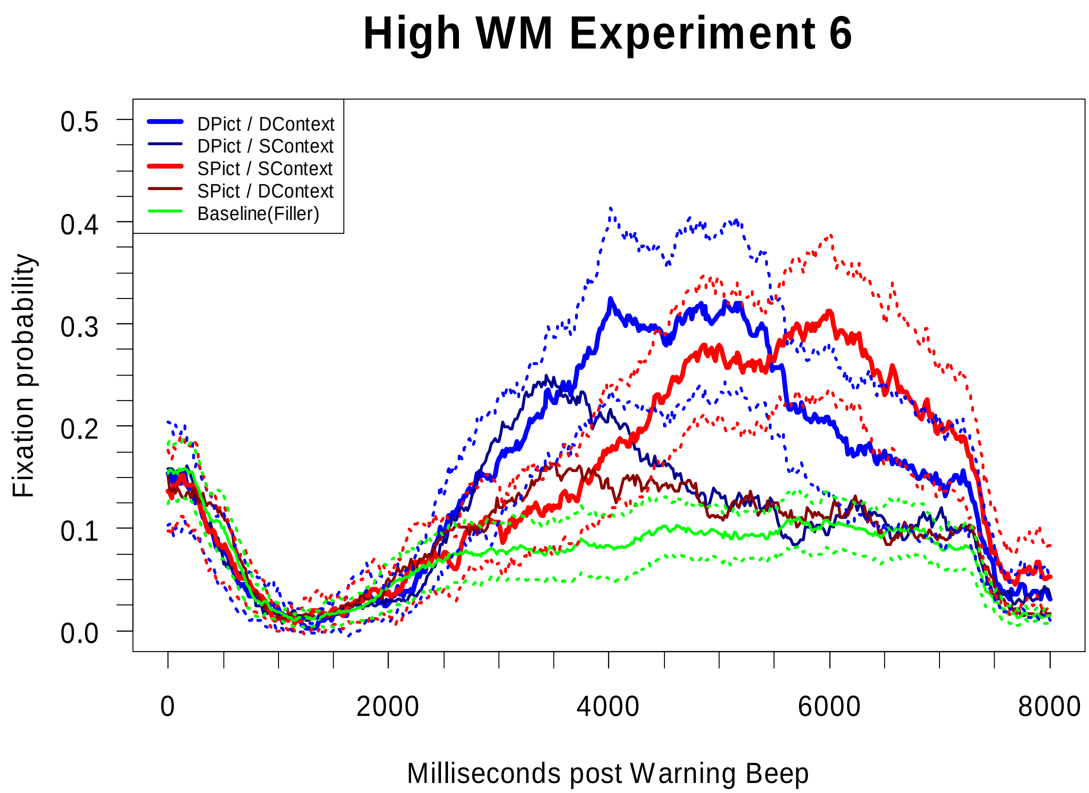

All Subjects, One Related Target
DPict / DReply
DPict / SReply
SPict / SReply
SPict / DReply
Baseline(Filler)
Fixation probability
0.0
0.1
0.2
0.3
0.4
0.5
0
2000
4000
6000
8000
Milliseconds post Warning Beep

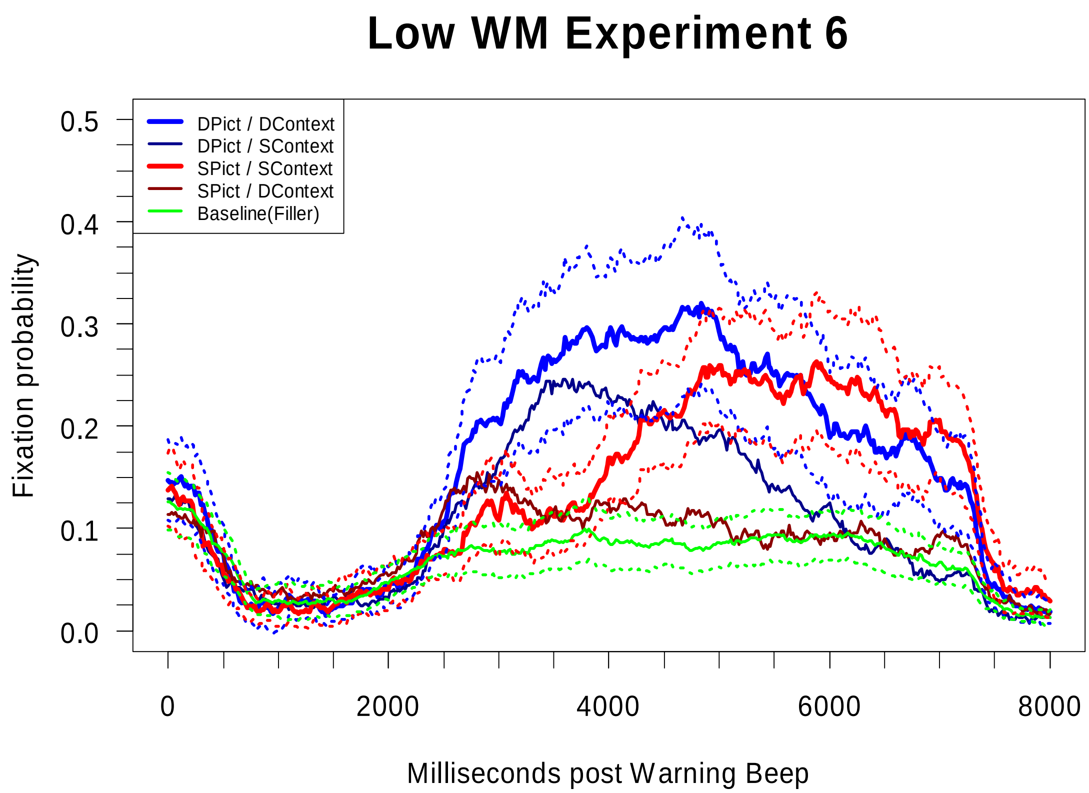

High WM, One Related Target
DPict / DReply
DPict / SReply
SPict / SReply
SPict / DReply
Baseline(Filler)
Fixation probability
0.0
0.1
0.2
0.3
0.4
0.5
0
2000
4000
6000
8000
Milliseconds post Warning Beep

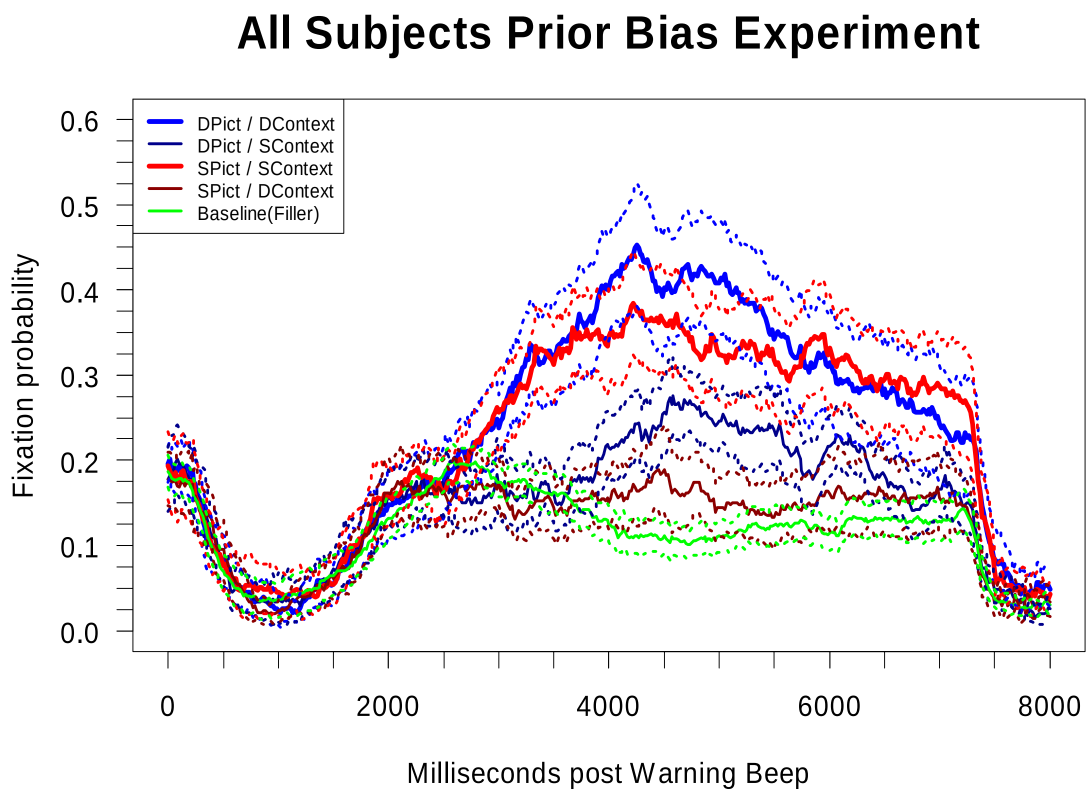


Low WM, One Related Target
DPict / DReply
DPict / SReply
SPict / SReply
SPict / DReply
Baseline(Filler)
Fixation probability
0.0
0.1
0.2
0.3
0.4
0.5
0
2000
4000
6000
8000
Milliseconds post Warning Beep

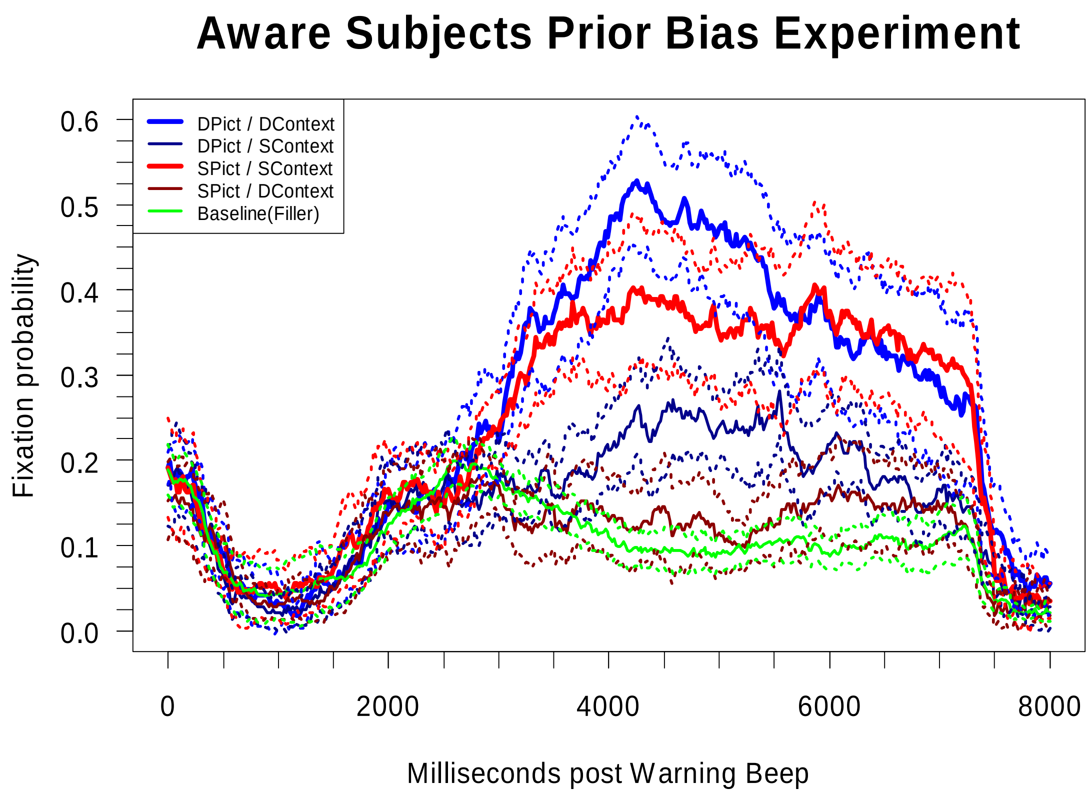

All Subjects Experiment 6
DPict / DContext
DPict / SContext
SPict / SContext
SPict / DContext
Baseline(Filler)
Fixation probability
0.0
0.1
0.2
0.3
0.4
0.5
0
2000
4000
6000
8000
Milliseconds post Warning Beep


High WM Experiment 6
DPict / DContext
DPict / SContext
SPict / SContext
SPict / DContext
Baseline(Filler)
Fixation probability
0.0
0.1
0.2
0.3
0.4
0.5
0
2000
4000
6000
8000
Milliseconds post Warning Beep

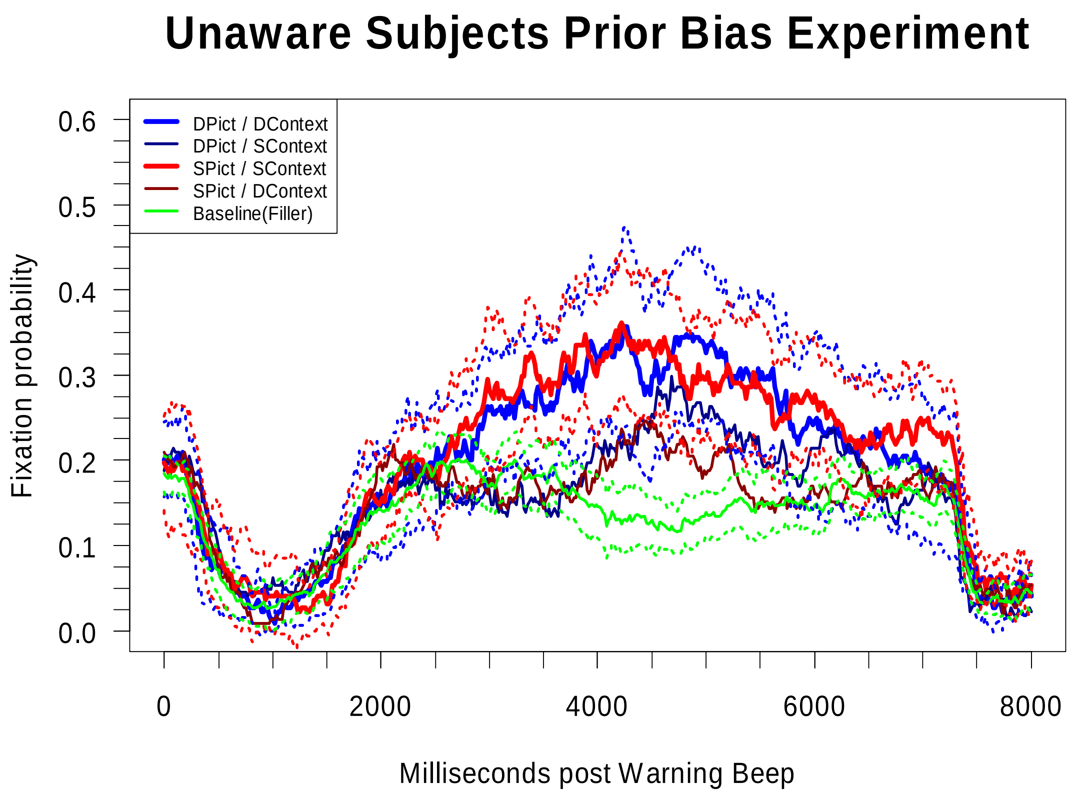

Low WM Experiment 6
DPict / DContext
DPict / SContext
SPict / SContext
SPict / DContext
Baseline(Filler)
Fixation probability
0.0
0.1
0.2
0.3
0.4
0.5
0
2000
4000
6000
8000
Milliseconds post Warning Beep



Note. Ninety-five percent confidence intervals are included for consistent and inconsistent targets, as well as the baseline.



Note. Ninety-five percent confidence intervals are included for consistent and inconsistent targets, as well as the baseline.


Unaware Subjects Prior Bias Experiment
DPict / DContext
DPict / SContext
SPict / SContext
SPict / DContext
Baseline(Filler)
Fixation probability
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0
2000
4000
6000
8000
Milliseconds post Warning Beep

VITA

Aaron Meyer was born in Granite City, Illinois. He received a B.A. in Psychology from Illinois College, a M.S. in Experimental Psychology from Illinois State University, and a Ph.D. in Psychology (Cognition and Neuroscience) from the University of Missouri-Columbia. He is married to Dawn Giuffre of Nazareth, Pennsylvania, and he is currently a postdoctoral researcher at the University of Illinois at Urbana-Champaign.