Monitoring Eye Movements to Uncover the Role of Visual Context in the Access to Verb-Complement Information During Sentence Comprehension

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ABSTRACT

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This study examined the role of sentence and visual context in the access to verb-complement information, using an eye-tracker paradigm. Two sets of sentences were contrasted, a highly constraining causative construction in which there was a close conceptual relation between the verb and its direct object (e.g. "The woman burned the candle"), and a neutral construction with a transitive perception verb (e.g. "The woman admired the candle"). Moreover, we conducted an object search task to monitor the time subjects took to look at the target object (e.g. "candle") when presented in isolation, using the same three probe points (onset of the noun, offset of the noun, and offset+200 ms). From these latter measurements, the saccade onsets to the target noun in the sentence experiment were subtracted in order to obtain a pure measurement of verb effects in the sentences. Subjects were asked to perform two different tasks; a memory matching task where they had prior viewing of the set of objects before the advent of the sentence, and a visual search task where the set of objects appeared only during the presentation of the sentence. Memory effects were then examined by contrasting the data collected from these two tasks. Results failed to support a statistically significant difference between these two types of sentence constructions, regardless of task, suggesting that verb-specific representations do not cause faster eye movements to objects related to typical complements of verbs. In conclusion, the language comprehension system appears to rely primarily on structural analyses of linguistic representations, which are independent from conceptual interpretation.

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Humans are quite proficient at recognizing speech and because recognizing words in an utterance is accomplished so rapidly and usually effortlessly, we often overlook how complex and important a part this skill plays in our daily lives. Psycholinguists have been concerned with a number of issues regarding language comprehension. Although many issues will be broached in this study, the main issue will be whether or not processes in language operate independently of one another, or whether they interact, and if so at what stage of the process. There are two strongly opposing views concerning how the language processing system is structured; the autonomous and the interactive views. They both agree that context plays an important role in spoken recognition, where they differ, however, is when and which types influence the processes involved in recognizing speech. The two broad categories of context include the representations computed from sensory input, and those constructed from previous knowledge (e.g. lexical, syntactic, semantic, and pragmatic).

Autonomous View on Word Recognition

According to the autonomous proponents, context cannot have its effect prior to the input being processed by the lexicon. The lexicon is like a mental dictionary that contains all the information we know about a word, including its phonology (sound), semantics (meaning), written appearance (orthography), and the syntactic roles in which it can partake. Thus, according to this view, context cannot be involved in generating alternative structures prior to lexical output, but rather can only contribute to the evaluation and integration of this output. Within this camp, however, there exist various models that differ in the extent to which the operations within the system operate independently.

In the model postulated by Forster (1979), there are several autonomous processing modules, one for each level within the language processing system (lexical, syntactic, and semantic). These modules are connected in a serial fashion, whereby higher levels can only process the output of the lower levels, but the output from the higher level modules cannot affect processing operations at the lower levels. Thus, the lexical access module produces an output consisting of lexical items, which is then used by the next module, the syntactic module. This module then uses this output, as well as the information within its own module to make a best estimate of the sentence structure that is possible given the available information. This output is then transferred to the next module for semantic interpretations by the semantic module. At no time, however, are the internal computations within each module made available to any of the other modules. Finally, when the sensory input uniquely specifies a word, the master file that contains all the internal properties is contacted and it is only at this point that its syntactic and semantic properties are evaluated against the context.

Another well known model is that proposed by Fodor (1983), which is formally known as modularity. In this model, there is only a single module called the language processing module. He argued that lateral flow of information is allowed within the different processing levels, but that information from other cognitive processes, such as world knowledge cannot penetrate the module. Thus, each system is informationally encapsulated in that the operations it performs have access only to the information in its own database and the type of information to which it is attuned, and not information by the cognitive processes which can penetrate the modules (i.e. no top-down interaction). An example that he used to demonstrate this argument, is the persistence of illusions (e.g. Mueller-Lyer Illusion) even after being aware that it is not what it appears to be. Fodor commented that the illusion does not simply disappear because we really want it to. Furthermore, he argues that there are three conditions that an experiment has to meet in order for it to provide clear evidence against modularity: 1) It must demonstrate the influence of background information in the modules computations which is exogenous to the module (i.e. information which is outside its own database); 2) The effect of background must be perceptual, and not postperceptual (i.e. the background information in perception is predictive); and 3) The cognitively penetrated system must be the one that takes care of perceptual analysis at all times, and not just in times where the stimulus is too degraded for the module to cope with (Fodor, 1983). Fodor also advocates that each module is domain specific and that the computational systems that deal with the production of language have not much in common with those that deal with the analysis of visual perception. Thus, these systems are autonomous. This model differs from Forster's model in that the autonomy principle only applies to the whole module and not the intermediate levels of processing.

Interactionist View on Word Recognition

Interactive models on the other hand, propose that information from different processes can interact with each other. There is no consensus, however, regarding the extent to which contextual information can affect processing within any of the linguistic levels.

In the model proposed by Morton (1969), expectations generated from higher-level representations affect the earliest phases of lexical processing by altering the activation level of the lexical candidates that have been accessed in parallel. Each candidate has its own resting level and accumulates corroborating perceptual or contextual evidence until it manages to pass its individual threshold. When this occurs the lexical candidate fires and the word is recognized. Moreover, according to this model, context can propose lexical candidates for consideration even before any sensory input has been received.

Others, however, such as Tyler & Marslen-Wilson (1977) proposed that context can only be used to dispose of candidates and not propose them. They argued that it was only when the sensory input made initial contact with the lexicon that lexical candidates were evaluated for their contextual appropriateness. Those that were incompatible with the context had their level of activation decay, until further corroborating evidence, which in turn reduced the set to only words which were contextually appropriate. Thus, the initial process of contacting the lexicon is autonomous, but the selection phase is interactive. Moreover, they argued that semantic and syntactic information are used simultaneously and interactively to develop a representation of a sentence as it is heard, rather than waiting until the syntactic segment is identified and processed. Each process acts as a check and guide for the other and causes just one out of several possible syntactic structures to be initially constructed.

Thus, as demonstrated from the degrees of the two classes of models, differentiating between these modules and interpreting results, can sometimes be quite difficult. The distinguishing factor remains, however, the point at which context can have an effect. Interactionists argue that context exerts its effect before or during the selection phase, while autonomists argue it can only occur after a word has been chosen as the best fit with the sensory input.

Type of Context

Frauenfelder & Tyler (1987) distinguished between two types of context; structural and non-structural. They define structural context "as that which results from constraints on the way which elements can be combined into higher-level units" (Frauenfelder & Tyler, 1987, p.12). Thus, the rules which govern each system determine which elements can be combined to form structural units. Non-structural context, does not result in a higher-level representation.

Intra-lexical effects is a non-structural context effect, regarding the impact recognition of one word can have upon the processing of another word which bears some relationship (phonological, morphological, syntactic, or semantic) with it. For example, the semantic properties of the word doctor primes or facilitates the processing of the semantically associated word nurse. Autonomists, such as Fodor argued that this is the only type of semantic context that can affect processes prior to recognition since this involves relations between items within a single level of the processing system. In contrast, lexical, syntactic, semantic, and interpretative context are structural context effects.

Lexical context effects refer to the influence that lexical representations have upon phonetic processing (Fraeunfelder & Tyler, 1987). For instance, Ganong (1980) presented subjects with phonemes varying along a continuum (e.g. k↔g) within a context (e.g. "__iss"). Results showed that subjects gave more word phoneme responses than nonword responses, suggesting that the lexical context influenced the processing of these phonemes. Autonomists argued, however, that lexical level is only used to evaluate the lower level of the sensory input, and suggests a revision if the analysis proves to be wrong. Thus, top-down flow of information involving multiple levels of the system is prohibited.

Syntactic context effects refer to the information available from processing the syntactic structure, which in turn contrains the syntactic properties of the upcoming words and their constituent structure (Frauenfelder, & Tyler, 1987). According to the authors, there appears to be a consensus between the autonomists and interactionists that this type of context often does not prove to be very useful since our grammar is so complex that many different syntactic categories (noun, verb, adverb, adjective) can follow a particular word.

Semantic context refers to context based on word and syntactic meaning. Marslen-Wilson (1984) found that words which were semantically appropriate for the context were identified more quickly, and were more frequently restored to its original form when mispronounced (e.g. "comsiny", rather than "company"), than those which were contextually inappropriate. Autonomists, however, argue that these results can be explained in terms of intra-lexical associations, and not some higher-order structural representations. Thus, as mentioned earlier, this type of effect does not violate autonomous models, since they occur within a single level of the language system. Yet, even if semantic context effects are found to be located in the early phases of lexical processing, this would violate the Forster (1979) model whereby this information can only play a role post-lexically, but not Fodor's (1983) model because it is located within the language module.

Syntactic Comprehension

How linguistic knowledge is used to create syntactic structure is also a highly debated subject between autonomists and interactionists. Autonomists, such as Frazier (1989) propose that listeners construct a single representation of a sentence based solely on grammatical principles. In the first stage the parser constructs a single phrase structure using the grammatical categories of the words in the sentence (e.g. subject, noun, verb). If this sequence of categories is compatible with multiple possibilities of phrase structures, the choice is determined by a processing strategy called minimal attachment. This principle states that in order to construct the simplest syntactic structure the new material needs to be attached unto the phrase structure tree using the minimal number of new nodes as possible. If after this step there are still multiple equally simple analyses, then a second principle is put into place, late closure. This principle directs the parser to pursue the main verb interpretation, independent of word meaning or discourse context (e.g. raced interpreted as the past tense of main verb in the sentence). After this first stage, other processing subsystems subsequently confirm or reject the initial syntactic analysis, and reanalyze if necessary. In contrast, interactionists such as MacDonald, Pearlmutter, & Seidenberg (1994) proposed that other factors, such as frequency of use, lexical structure, plausibility, and context, also influence how sentences are comprehended.

The most widely studied type of syntactic ambiguity is the occurrence of garden path sentences. A famous example of this phenomenon is "The horse raced past the barn fell". According to Frazier (1989) the sentence is interpreted into the structurally simplest analysis using the principles of minimal attachment (simplest structure which results in there being the fewest new nodes possible) and late-closure (attach new items into the phrase currently being processed). When the unexpected word fell is reached, however, the system realizes that the analysis is wrong and goes back to reanalyze the sentence. Moreover, Fodor (1983) argued that since the parser is isolated the single simplest parse is pursued even in the presence of prior context favoring an alternative analysis.

In contrast, Crain & Steedman (1985) proposed that garden paths arise because semantic principles guide the selection of which interpretation, made available by the listener's syntactic knowledge, is selected. They argued "that analyzing a phrase as a modifer of a definite [noun phrase] NP presupposes the existence of contrasting potential referents, and claimed that in isolation a modifier interpretation is semantically unpreferred because the reader/listener lacks the presupposed referents" (Clifton, & Duffy, 2001, p.181). For instance, with the sentence "The horse raced past the barn fell", the listener needs to know that there was more than one horse and that it was only the one that raced passed the barn that fell. Thus, they proposed if the listeners were presented with a context that provided these referents then the garden path effects would disappear.

Altmann & Steedman (1988) examined this further by presenting subjects with short paragraphs such as:

> [1] "A burglar was trying to break into a house and had a credit card in his hand. He wanted to open a door. He found a door which had a faulty lock and a window which had a cracked frame".

In this paragraph there were two referents (door and window). While in another condition, the referents were the same (door). This was accomplished by using the same paragraph, but with a different final sentence.

[2] ...He found a door which had a faulty lock and a door which had a cracked frame.

Subjects saw one of these two paragraphs in combination with one of the following sentences.

(a) The burglar opened the door with the credit card and quickly slipped inside.

(b) The burglar opened the door with the faulty lock and quickly slipped inside.

The critical element in the sentence is the word with. In the presence of two referents (context 2), they argue, that the word "with" has to be interpreted as the beginning of a prepositional phrase (PP) that is attached to the noun phrase (NP) "the door". While in the presence of one referent (context 1) the PP will be attached directly to the verb phrase as the instrument used to open the door. According to Frazier this would be the simplest structure. Thus, they hypothesized that sentence (b) should be more compatible with context [2] because it disambiguates which door is being opened. While sentence (a) should be more compatible with context [1] because there is only one door so there is no need to specify which door is being opened. Results showed that subjects were faster at reading (a) with context [1] and (b) with context [2], suggesting that context influenced the parsing of the sentence.

Visual Context Effects in Sentence Comprehension

In contrast to the Altmann & Steedman (1988) study, which examined the effects of written context, Eberhard, Spivey-Knowlton, Sedivy, & Tanenhaus (1995) investigated the role of visual context in spoken language comprehension. Eberhard et al. gave an example of a noun phrase "the large beach ball". The modularists would argue that the referent of this phrase could not be understood until the noun ball. This may be a safe interpretation in decontextualized situations, however if a listener is faced visually with two beach balls, one small and one big, it is reasonable, they argue, to assume that listeners will already know the relevant object after hearing the word large. Olson (1970) argues that speakers use different expressions to refer to the same object in different contexts in order to provide their listeners with just the necessary information for distinguishing the intended referent from the set of alternatives. In fact, in the context just mentioned, the information that the ball is a beach ball is unnecessary since the intended referent would already be distinguished simply with the expression "large ball". In order to examine contextual dependency in language comprehension in further depth, they used a new methodology. This involved monitoring listener's eye movements as they followed instructions telling them to move or touch common objects in a display. This new method, they proposed, allowed them to measure on-line spoken language comprehension, as it occurs in natural situational contexts, and as it unfolds over time. They argued that there were two reasons why this paradigm is so useful.

> "First, the visual context is available for the subject to interrogate as the spoken language unfolds over time, and because the message directs the listener to interact with the context, the context is necessarily relevant to the comprehension process. This contrasts with a linguistically introduced context, which must be represented in memory and depending upon the experimental task, may or may not be immediately accessible or perceived as relevant by the reader or listener.

Secondly, in all the work we have conducted to date, we have found that subjects' eye movements to objects are closely time locked to the spoken words that refer to those objects" (Eberhard, et al. 1995, p. 411).

In the first experiment, subjects were given spoken instructions to touch various blocks in a display. These blocks differed along marking, color, and shape, and the spoken noun phrases in the instructions referred to each of those dimensions. For instance "Touch the starred yellow square". The instructions were created to disambiguate at different points within the noun phrase. The researchers found that the subjects processed the instructions incrementally, making saccadic eye movements to the objects immediately after hearing the relevant words in the instruction. These same results were found in a second experiment with more complex instructions. Subjects were asked to manipulate seven miniature playing cards and given such instructions as, "Put the five of hearts that is below the eight of clubs above the three of diamonds". They concluded from these two experiments that eye movements provided insight into the mental processes that accompany language comprehension.

In a third experiment, Eberhard et al. examined whether the amount of spoken input a listener needed to establish reference would be influenced by the names of the referents in the visual context. Subjects were instructed to move common objects in a display (e.g. "Pick up the candy. Now put it above the fork"), whereby on some trials the target object would appear on the display with a competitor object whose name shared the initial sound (e.g. "candle" and "candy"). They found that the mean time to initiate an eye movement to the correct object was 145 ms from the end of the word, when there was no other object with a similar name onset, while when an object with a similar name onset was present, mean time was 230 ms. They concluded that because it takes about 200 ms to program a saccade, these results demonstrated that the listeners identified the object before hearing the end of the word, when none of the other objects had a similar name.

In their final experiment, Eberhard et al. wanted to examine whether visual context would affect the syntactic processing of an instruction. The authors used prepositional phrase (PP) ambiguities, such as "Put the saltshaker on the envelope in the bowl". In this case the first PP (on the envelope) is ambiguous, for the listener does not know whether the speaker intends it to be the destination of the verb put (i.e. where it will be moved to), or the modifier specifying the properties of the saltshaker (i.e. that it is currently on the envelope). According to the encapsulated parsing models, the first PP should be interpreted as the goal rather than the modifier of the theme, regardless of whether the visual context supports the modifier interpretation, because of the minimal attachment principle, and because the destination argument is an obligatory argument for the verb put (Eberhard et al., 1995). Subjects were presented with PP ambiguity instructions, as mentioned above, as well as with unambiguous control instructions, such as "Put the saltshaker that's on the envelope in the bowl". The visual context consisted of two possible displays, the one and two referent contexts (see Figure 1). The one-referent context supported the destination interpretation, because there is only one saltshaker the listeners assume that "on the envelope" refers to the destination. The two-referent context supported the modification interpretation, because there are two saltshakers the listeners assume that "on the envelope" specifies the modifier (i.e. which of the two saltshakers needs to be moved).

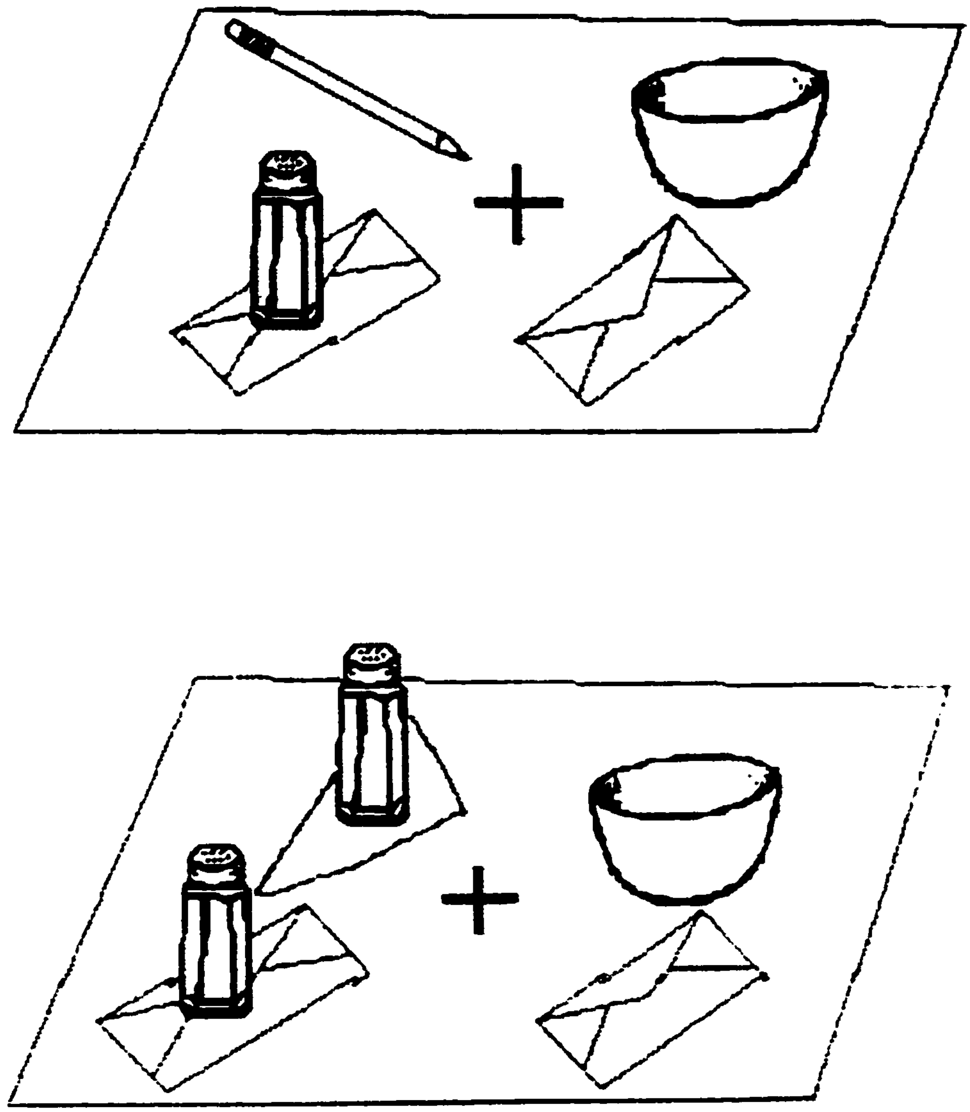
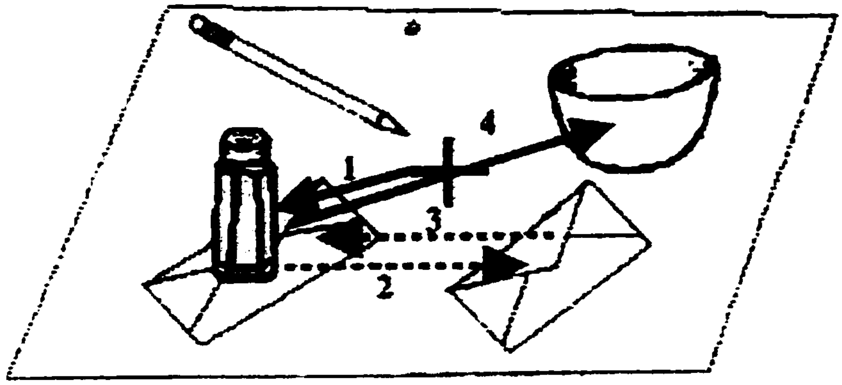
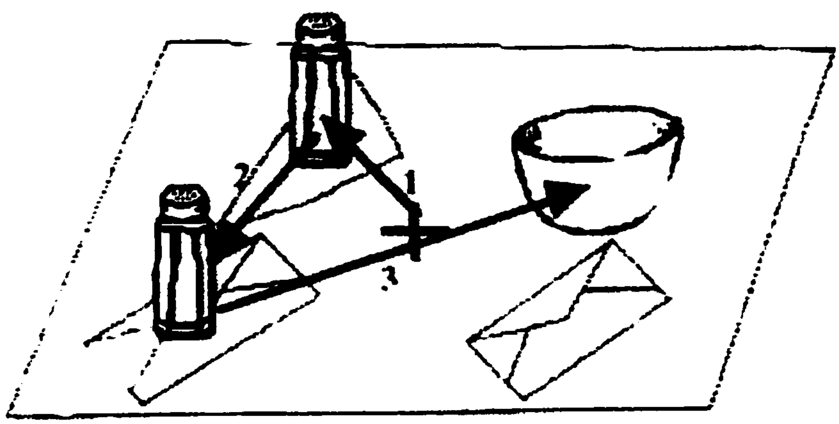


Figure 1. Example of One and Two-referent displays. (Based on Eberhard, et al. 1995, p 427-428).

The results showed different eye-movement patterns when the ambiguous instruction was given in the two types of contexts (see Figure 2). In the one-referent condition, subjects first looked at the target object (saltshaker) 500 ms after hearing "saltshaker". They then looked at the incorrect goal referent (the envelope) 484 ms after hearing "envelope", thus providing evidence that they interpreted it as the destination. With the nonambiguous instruction, however, they never looked at the incorrect goal referent, instead they looked to the correct goal referent shortly after hearing "bowl". In the two-referent condition, the subjects looked at both saltshakers while hearing "the saltshaker on the envelope", indicating that the intended referent could not be identified until the word "envelope" (i.e. interpreted it as the modifier). They rarely looked at the modifier referent (the envelope), instead they looked at the correct goal referent (the bowl) shortly after hearing "bowl". This pattern was similar to the nonambiguous instruction. They concluded "that in natural contexts, people seek to establish reference with respect to their behavioral goals during the earliest moments of linguistic processing...and [that] referentially relevant nonlinguistic information immediately affects the manner in which the linguistic input is initially structured" (Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995). Furthermore, Tanenhaus et al. (1995) argued that models which propose that grammatical constraints are integrated into processing systems whereby linguistic and nonlinguistic information interact as the linguistic input is processed would be more accurate than those that propose encapsulated linguistic subsystems.



a)



b)

Figure 2. Eye-movements for (a) One and (2) Two-referent conditions. (Based on Eberhard, et al. 1995, p 430).

Selection Restrictions

Chomsky (1965) proposed that there are restrictions to which words are necessary in order to prevent the generation of deviant sentences. He argued that there are two kinds of selection restrictions. The first occurs when the syntactic structure of a string limits the selection of possible words. He proposed that "strict subcategorization features" categorize major word classes (e.g. nouns, verbs) into sub-classes according to the syntactic frames in which they can occur. For example, transitive verbs have the feature (....NP) which indicates that only verbs with this contextual feature can appear in this position (i.e. in a sentence with a direct object). The second, "selectional features" define the context in which a word can be selected in terms of the lexical features of the other words occurring in the string. He proposed that each noun has associated with it such features as count or mass, animate or inanimate, human or nonhuman, male or female, and so on. While verbs and adjectives have contextual features associated with them, indicating the features of nouns with which they can occur. For example, "John" would be assigned the features (N, +animate, +human, +male, etc...) and the verb "frighten" would have the features (V, (...NP)), (+abstract....+animate), (+animate...+animate), indicating that frighten is a verb, a transitive verb, and that it can occur with either an abstract subject and an animate object, or with an animate subject and an animate object (Greene, 1972). Moreover, Chomsky claims that breaking a strict subcategorization rule leads to worse deviations from grammaticalness than breaking selectional rules. He concluded that whether these selectional rules are syntactic or semantic constraints was still open for debate. For instance, his famous syntactically correct yet meaningless sentence "colourless green ideas sleep furiously", according to the selectional rules this sentence would be considered ungrammatical because "sleep" requires an animate subject, while "green" can only be applied to physical objects. Thus, depending on whether these selectional restrictions are syntactic or semantic constraints, such a sentence is allowed to be generated as syntactically permissible, which would then require the semantic components to reveal the anomalies involved in this sentence.

Verb Guidance

Detailed properties of verbs, in particular the kind of arguments they can accept (subcategorization properties) has shown to influence parsing (Clifton, Frazier, & Connine, 1984, MacDonald, Pearlmutter, & Seidenberg, 1994), and constitute the central element over which we build conceptual-structure representations of utterances (Jackendoff, 1990). For instance, with the sentence "After the private had (saluted/fainted) the sergeant he requested permission to end the exercise", the verb "saluted" is acceptable, but not "fainted". According to the subcategorization features of the verb "saluted" it can be used either transitively or intransitively, whereas "fainted" cannot be used with a direct object.

There are three classes of models regarding how lexical information, particularly the subcategorization properties of verbs is used in the construction of syntactic structures; parallel version and serial version of assembly-directing models, and the structure-checking model (Mitchell, 1989).

In the parallel version the lexical information is used to guide the process of constructing syntactic structures and when there is more than one alternative analysis they are pursued in parallel. Fodor, Garrett, and Bever (1968) proposed that the subcategorization properties of the verb are used to develop all lines of analysis consistent with this information. For instance if a sentence contains a transitive verb, the parser would concentrate on direct-object constructions. Moreover, they predicted that less constraining verbs would be more difficult to process due to the costs associated with sustaining multiple analyses.

In the serial models lexical information is used to guide the structural analysis of the sentence and the parser uses this information to select only the most probable analysis. If this analysis later proves to be wrong, then the lexical selection procedures are used to propose a second most probable structure, until it is compatible with the other information. Ford, Bresnan, & Kaplan (1982) propose that some words have different lexical forms, and that each of these forms has different strengths. When the parser encounters these words, it selects the one marked as being the most salient and uses it as the framework for syntactic analysis of the rest of the sentence. Moreover, they do not predict that the processing load will be reduced with more constraining verbs, since the first analysis is independent of the number of alternatives.

In the structure-checking models the structural analysis is set up without the guiding of lexical information, but rather use the major syntactic categories, parsing strategies and conventions. It is only during the procedure of checking the submitted structure to the requirements of the grammar that lexical information comes into play. For instance, it may check whether the proposed structure matches the subcategorization of the verb, or that it is compatible with the verb number, gender, and case agreement. Many models have been proposed, and all vary with respect to when during the processing of the sentence it is checked (end of sentence, phrase, or word).

Thematic Roles in Sentence Comprehension

Tanenhaus, Carlson, & Trueswell (1989) studied how different types of lexical information, in particular thematic roles, are used to guide sentence comprehension. Thematic roles (e.g. agent, theme, and location) refer to the semantic roles that the syntactic complements (e.g. subject NP, object NP, and locative PP) or arguments of verbs can play (Tanenhaus et al., 1989). They gave as an example the verb "donate", which gives multiple sources of information; the meaning or sense of the verb (means to give), the thematic roles associated with the verb (requires a donor or agent, a patient or recipient, and a theme or the object that is donated), and the argument structure of the verb (requires at least two argument NP, and an optional NP). For instance a sentence which would satisfy these criteria is, "John (subject NP/agent) donated fifty dollars (object NP/theme) to his favourite charity (PP/recipient)".

Altmann and Kamide (1999) proposed an experiment that could demonstrate that information extracted from the verb could serve to directly identify a referent, just as the adjectives "large" or "beach", in the example mentioned above, served to narrow down which ball was being referred to by the speaker, before the actual onset of the head noun "ball". Subjects were presented with semi-realistic visual scenes made up of color drawings (see Figure 3 for an example) and one of two possible sentences. In this scene example there is a young boy sitting on the floor around which were various items (toy train, toy car, birthday cake and a ball). One sentence contained a verb that due to its selectional restrictions allowed only a single object in the visual scene to be the post-verbal target object (e.g. "The boy will eat the cake"), while the other sentence contained a verb that allowed at least four of the visual objects (e.g. "The boy will move the cake")

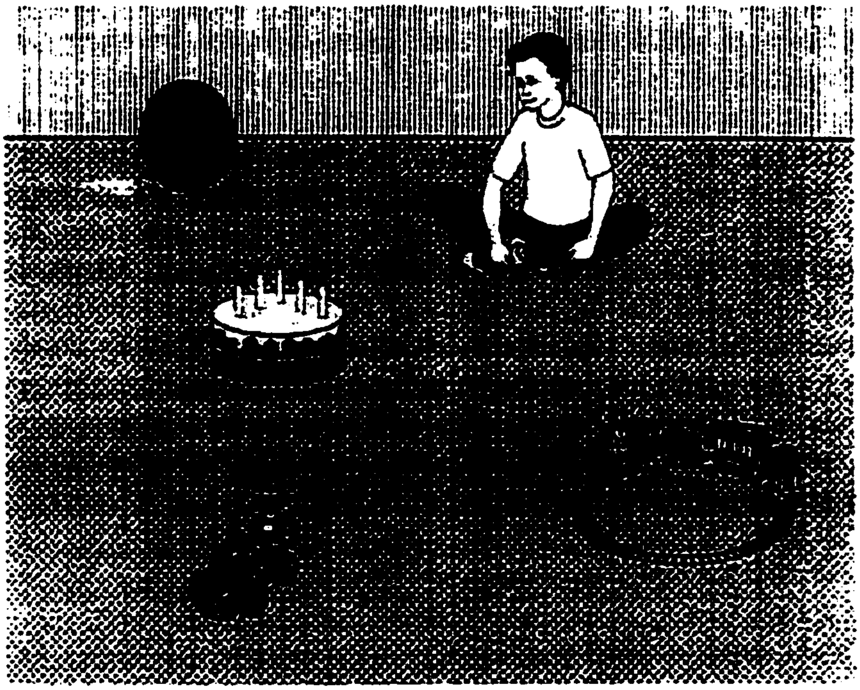


Figure 3. Example of a scene. (Based on Altmann and Kamide, 1999, p 250).

to be the post-verbal target object. Filler items were added whereby the target object referred to in the sentence was not present. Subjects' task was to indicate by a "yes" or "no" response whether the target object was present, meanwhile their eye-movements were recorded. Furthermore, saccades were measured relative to four probe points: verb onset; verb offset; determiner onset; and noun onset. Results showed that when verbs highly constrain the nature of noun complement, saccade onset to the target object was significantly faster than with less-constraining verbs. In fact the first saccade was launched well before the onset of the post-verb noun in the constraining condition, while in the less-constraining condition the saccade was launched after its onset. Altmann and Kamide (1999) concluded that these results suggest that the language processor can activate representations due to the predictive nature of verb arguments, and that these arguments are evaluated according to the thematic fit between the entities in the current context in which the unfolding is occurring and the verb.

Rationale and Purpose of this Study

There have been only a handful of attempts that have investigated the integration between visual and linguistic representations (studies mentioned earlier), and of these few studies only one study has used the eye-tracking technique to look at the role of verb information in parsing and semantic interpretation (Altmann, and Kamide, 1999). This study focuses on the role of visual representations in the access to argument and conceptual structures of verbs during sentence processing. I used an eye-tracking paradigm in which subjects heard sentences while looking at pictures of objects displayed on a computer screen. This study differs from Altmann and Kamide (1999) in seven important ways.

First, in Altmann and Kamide's study subjects were free to move their eyes prior to verb onset. Thus subjects eye gaze position, relative to the target object at verb onset was not held constant across trials. When using time to initiate a saccade to the target object as your measurement, it is important to control eye gaze position, because as Altmann and Kamide mentioned, in certain trials subjects were already fixating the target object at the onset of the verb. Furthermore, the distance between the objects presented in the scene was not equidistant. In order to prevent this occurrence, I controlled saccade onsets and fixations by presenting a red dot on the screen placed equidistant from a set of six pictures of objects. Subjects were required to fixate this dot until the dot turned green, which alerted them that they were now free to move their eyes.

Second, in their study they did not collect normative data for the pictures of the target objects they chose. Thus, it is not certain whether the names that the subjects were assigning to each picture were the ones intended by the experimenters. I controlled for this potential confound by conducting an experiment whereby subjects were asked to name the pictures, as they flashed on the screen, which we chose to represent the direct objects of verbs.

Third, Altmann & Kamide did not collect normative data for their conceptually related noun-verb pairs. Tesolin & De Almeida (2000) collected the norms for this study by presenting subjects with sentence frames that they were asked to fill in using the most appropriate noun. The frames were either "The person closed the ____" or "The _____ closed". Moreover, additional subjects were presented with the verbs in isolation and asked to indicate its most appropriate associate (e.g. "spill____"). If the strong verb associates matched the most appropriate noun they were eliminated from the set. This created a final set of 24 syntactically and conceptually related verb-noun pairs (e.g. "spill-milk"). Because Altamann & Kamide did not collect these normative data, their results may be explained by stronger verb associations in the constraining conditions (e.g. "eat-cake"), than the less constraining conditions (e.g. "move-cake").

Fourth, in addition to the picture of the target noun related to the verb, the sets of pictures contained linguistic (phonological), conceptual (semantically related to the target), and visual (shape and color) competitors. Through the use of these competitors, it became possible to examine which representations (linguistic, conceptual, or visual) became active as soon as information about lexical alternatives began to be available.

Fifth, subjects were asked to perform two different tasks. In the memory matching task, subjects viewed the set of objects before the advent of the sentence, while in the visual search task subjects saw the set of objects one of three probe points during the presentation of the sentence. The effects of prior viewing, and location knowledge were then examined by contrasting the data collected from these two tasks.

Sixth, Altmann and Kamide used semi-realistic scenes. There is however a large confound in some of their scenes, as in the example they provided (see Figure 3). The subject in this scene (i.e. the boy) is looking directly at the target object (i.e. birthday cake). This also occurred in two other scenes. Thus, even before the presentation of the verb subjects could deduce the identity of the target object. In this study the pictures of objects were presented in a circular pattern, with no picture representing the subject in the sentence, in order to prevent providing subjects with unwanted additional cues.

Seventh, Altmann and Kamide did not restrict subject's head movements, which is important to control in order to keep the distance between the screen and the subject's eyes constant, as well as make certain that the subjects are indeed looking at the display in front of them throughout the experiment. In this study subjects' head movements were restricted by having them place their head on a chin rest 57 cm from the monitor.

In this study, two sets of sentences were contrasted, a highly constraining causative construction in which there was a close conceptual relation between the verb and its direct object (e.g. "The woman burned the candle"), and a neutral construction, with a transitive perception verb (e.g. "The woman admired the candle"). In the burn case the visual display will contain only two burnable objects (candle and lamp [semantic competitor]). If the verb is utilized to narrow down the set of available referents to those which satisfy its constraint, this should result in eye movements to either of these two burnable objects at the onset of the noun. In the admire case, however, the visual display will contain all objects which are admirable. Thus, by contrasting the data from each type of sentence construction it was possible to examine whether the semantic information extracted from the highly constraining causative verb was able to guide visual attention towards the appropriate object in the visual display even before the semantic properties of the direct object become available. Furthermore, I conducted an object search task to monitor the time subjects took to look at the target object (e.g. "candle") when presented in isolation (i.e. not within a sentence), using the same three probe points. The measurements of saccade onsets to the target noun in the sentence experiment were then subtracted from the saccade time for the words in isolation in order to obtain a pure measurement of verb effects in the sentences. In Altmann and Kamide's study no measures were taken to obtain these pure measurement of verb effects.

Experiment 1

Experiment 1a

In this experiment, I examined whether the pictures of objects chosen to represent the direct objects of verbs and their corresponding competitors in the subsequent experiments, were named correctly (i.e. same names I used to label each object) and if the objects were equally identifiable (i.e. with similar naming times and percent correct). Each picture was presented successively at the center of the screen and subjects were asked to name each object as quickly as possible. When subjects responded correctly within the time allotted (2500 ms), the picture of the object was kept for the subsequent experiments.

Method

Subjects. Five Concordia Psychology undergraduate students participated in this experiment. They participated either for course credit or for $5.00. All were native speakers of English and had normal or corrected-to-normal vision (20/20 Snellen)

Apparatus and Stimuli. The experiment was conducted on a Macintosh G4 computer with a 21" Sony color monitor with a 75 Hertz (Hz) refresh rate. The resolution was set at 1152 x 870 pixels. Stimulus presentation was done using PsyScope (Cohen, MacWhinney, Flatt, & Provost, 1993) and data were collected by a unidirectional microphone attached to the voice activated relay port of a CMU button box. The fixation point was a small white (luminance = 58.31 cd/m^2) asterisk (Chicago 18 points). The stimuli consisted of 144 colored pictures of objects chosen from Hemera's Photo Objects Premium Image Collection CDs version 2.02 (see Appendix A). The pictures were rectangular and scaled to fit 150 pixels in the horizontal and/or the vertical, depending on the overall shape of the object. For instance, a vertically elongated object such as a pencil would be 150 pixels in height and its width would be scaled to fit according to its original measurements. The pictures of objects were situated in the center of the screen. The background of the pictures was grey (luminance = 12.89 cd/m^2) and the rest of the screen was black with a luminance of 0.250 cd/m^2 (see Figure 4 for a schematic arrangement). Each picture of an object belonged to one of six categories: noun (target object); phonological (object with same phonological onset as the target object); semantic (object within the same category as the target object); shape (object similar in shape to the target object); color (object similar in color to the target object); and random (object unrelated to the target object). Subjects responded verbally, and their responses were recorded by a mini tape recorder.

Procedure. The experiment took place in a dimly lit room in the Vision Lab at Concordia University. The experiment was divided into two sessions, six practice trials and 144 experimental trials and lasted approximately 10 minutes. After completion of the consent form (see Appendix B1), subjects were presented the instructions on the screen (see Appendix C1). I then answered any questions they may have had. After the practice trials, as a reminder of the task at hand, subjects received a shorter version of the instructions (see Appendix C2). The subjects were seated in a chair with their head placed on a chin/forehead rest, 57 cm from the computer monitor.

Each trial begun with the presentation of an asterisk at the center of the screen that served as a fixation point. The asterisk was shown for 1000 ms and then replaced by the picture of an object for 2500 ms or until the subject responded. The subjects' task

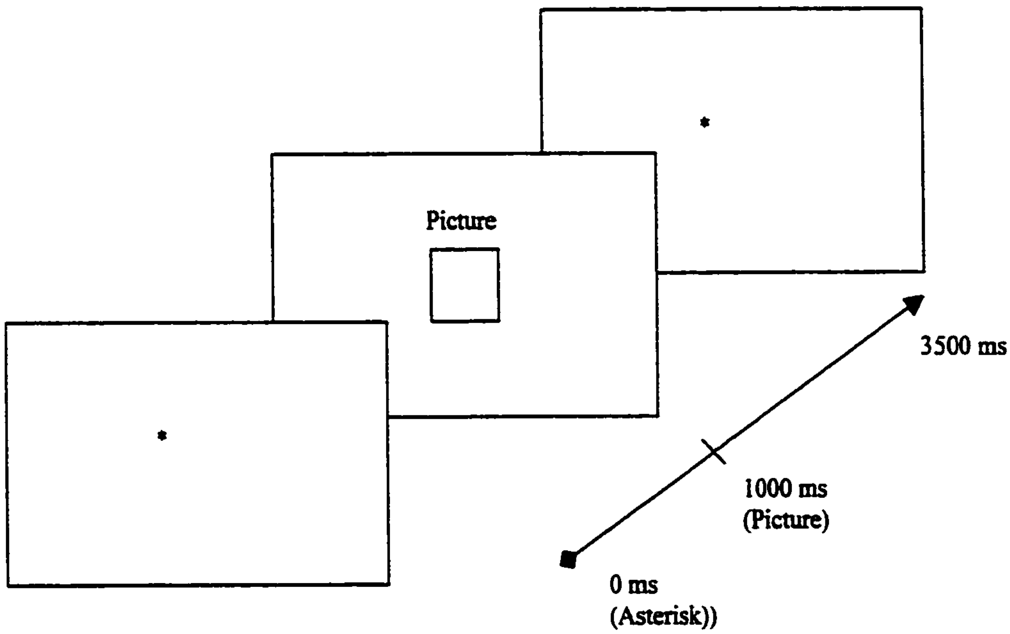


Figure 4. Schematic Representation of a sequence of stimuli in Experiment 1a.

was to name the picture of the object as quickly and clearly as possible by speaking into the microphone. They were informed that as soon as the computer recorded the response they would hear a beep. If no beep was heard then the computer was not able to record the response, and it skipped to the next trial.

Results and Discussion

Results for each subject are shown in Figure 5. Each bar represents the percentage of correct responses (responses which matched the names intended by the experimenter) across all trials. The data indicate that subjects on average responded correctly to 82.87% of the pictures. Furthermore, as shown in Figure 6 subjects took on average 1080 ms to name each picture of an object. I analyzed the data using a one-way between measures analysis of variance (ANOVA), with an alpha level of .05 significance (see Appendix D, Table 1). There was no significant difference between the six different categories of objects $F(5,24)= 0.801$, $p = 0.560$. This suggests that the pictures of objects were equally identifiable, regardless of the category to which they belonged.

There is a possible confound for the type of task that was chosen for this experiment. In our subsequent experiments the subjects' task will not involve naming the picture of objects on the screen but only moving their eyes to the picture of the object they just heard through headphones. This was corrected in Experiment 1b, by having subjects choose from among three pictures of objects, the one that corresponded to the object that was just uttered through the headphones. This was done only for the pictures of objects that were not named correctly or within the time allotted less than 60%

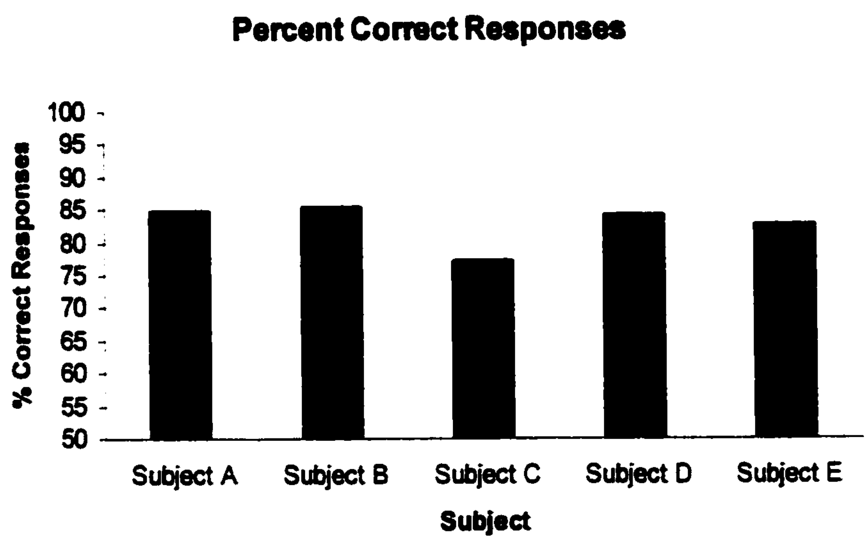


Figure 5. Percent correct responses to naming task in Experiment 1a, across subjects.

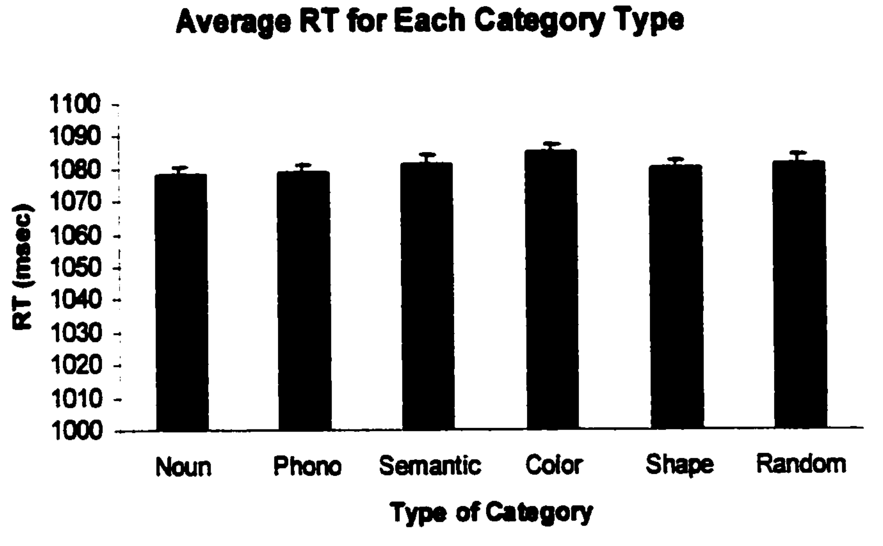


Figure 6. Average RT for each category of objects in Experiment 1a.

of the time in Experiment 1a (36 pictures of objects).

Experiment 1 b

In this experiment I changed the naming task into a matching task and retested the subjects with the pictures of objects that were unnamed or named incorrectly more than 40% of the time. Subjects' task was to indicate which of three pictures of objects matched the word just heard through headphones.

Method

Subjects. Three Concordia Psychology undergraduate students participated in this experiment. They participated either for course credit or for $5.00. All were native speakers of English and had normal or corrected-to-normal vision (20/20 Snellen)

Apparatus and Stimuli. The experiment was conducted using the same apparatus as in Experiment 1a, with the exception that the responses were collected using a button press on the CMU button box, which has three buttons. The stimuli consisted of 46 target colored pictures of objects. The pictures consisted either of the problematic pictures originally shown in Experiment 1a (26), newly chosen pictures representing those same objects (15) or newly chosen pictures representing different objects (5). The 92 competitor pictures were those that were identified greater than 60% of the time in Experiment 1a. One picture was presented at the center of the screen with the other two pictures on each side at a horizontal distance of 336 pixels (see Figure 7 for a schematic representation). The names of the objects were verbally recorded by a female voice, using SoundEdit16 software, on a Macintosh G4 computer.

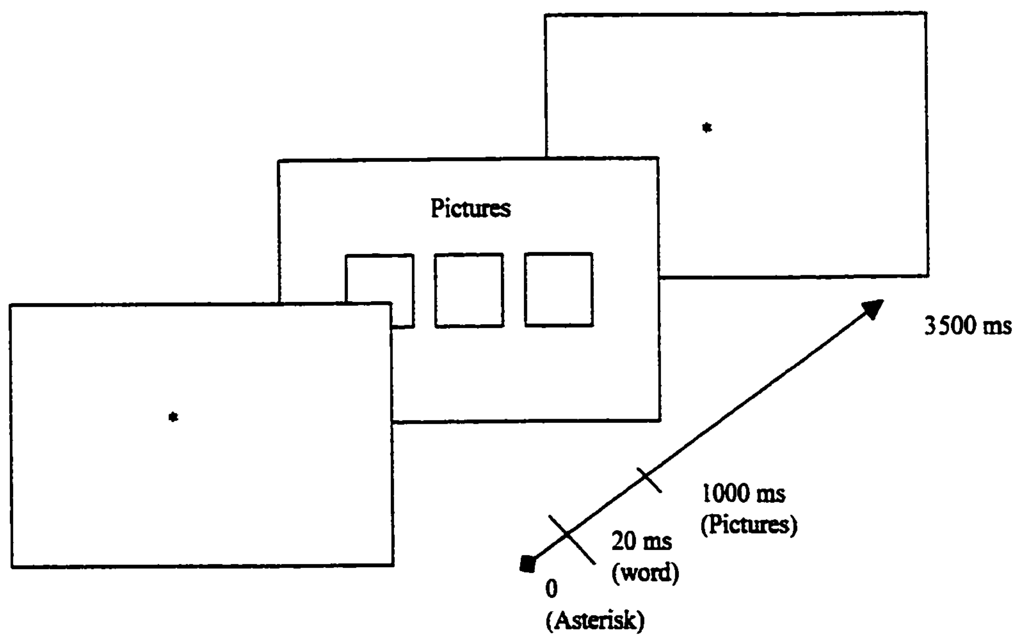


Figure 7. Schematic Representation of a sequence of stimuli in Experiment 1b.

Procedure. The experiment was divided into two sessions, three practice trials and 46 experimental trials and lasted approximately 5 min. After completion of the consent form (see Appendix B2), subjects were presented the instructions on the screen (see Appendix C3). I then answered any questions they may have had. After the practice trials, as a reminder of the task at hand, subjects received a shorter version of the instructions (see Appendix C4). The subjects were seated in a chair with their head placed on a chin/forehead rest, 57 cm from the computer monitor, with headphones placed on their ears.

Subjects were asked to fixate on the asterisk at the center of the screen. The asterisk was shown at the beginning of each trial for 1000 ms and then replaced by three pictures of objects for 2500 ms or until the subjects responded. The target objects were uttered 20 ms after the onset of the asterisk. The subjects' task was to press the button that corresponded to the picture of the object just heard (e.g. left button pressed if target object is the leftmost picture). The computer recorded the subjects' responses.

Results and Discussion

The results show that subjects responded correctly to all the target pictures of objects. Thus, we examined RTs and chose the pictures that produced the shortest RTs. Of the original 36 pictures in Experiment 1a that were problematic, 20 were kept and the remaining were replaced by either its complement (11) or a new picture of an object (5) (see Appendix A).

With these normative data collected I was then certain that the names that the subjects were assigning to each picture matched the ones that were intended to represent the direct objects of verbs and its linguistic, visual and conceptual competitors.

Experiment 2

In this experiment I conducted an object search task to monitor the time subjects took to look at the target object (e.g. "candle") when presented in isolation (i.e. not within a sentence), at three probe points (onset, offset and offset + 200 ms of the target object). The measurements of saccade onsets to the target noun in the sentence experiment (Experiment 4) will be subtracted from the saccade time for the words in isolation in order to obtain a pure measurement of verb effects in the sentences. This study was a basic two factors repeated measures design, the factors being probe point (time delay between the presentation of the word orally and the onset of the pictures of objects, with three levels: onset, offset and offset+200 ms of the target object) and type of objects (six levels, target object, color, phonological, semantic and random competitors, same as in Experiment 1a).

Method

Subjects. Nine Concordia Psychology undergraduate students participated in this experiment. They participated either for course credit or for $5.00. All were native speakers of English and had normal or corrected-to-normal vision (20/20 Snellen).

Apparatus and Stimuli. The experiments were conducted on a Macintosh G4 computer with a 21" color monitor with a 75 Hz refresh rate. Eye movements were recorded using an EyeLink eye tracker. The fixation point was either an asterisk (Chicago 24 pts), red dot (radius= 13.5 pixels) or a green dot (radius= 13.5 pixels). The stimuli consisted of 24 sets of six pictures of objects (144 pictures chosen in Experiment 1a and 1b with the same size dimensions) [see Appendix A]. The six pictures were presented in a circular arrangement (see Figure 8 for a schematic representation). One picture was presented above fixation at 0 degrees, below fixation at 180 degrees, two pictures to the right of fixation at 60 and 120 degrees, and two to the left of fixation at 240 and 300 degrees. The sentences were first recorded unto the Macintosh G4 and then the target words (direct objects of verbs) were extracted from these. Subjects responded on a button box, once they were fixated on the target object.

Procedure. The experiment was divided into three sessions, eye tracker calibration, five practice trials and 24 experimental trials and lasted approximately 15 minutes. The eye tracker calibration consisted of the following steps: the camera was placed in front of the left eye so that the eye was correctly centered; the threshold for the pupil was set; subjects were then asked to follow a dot that appeared randomly at seven set positions on the screen to assure the camera was correctly set; and finally the drift correction of the pupil was measured. After completion of the consent form (see Appendix B3), subjects were then presented the instructions on the screen (see Appendix C5). The experimenter answered any questions they may have had. After the practice trials, as a reminder of the task at hand, subjects received a shorter version of the instructions (see Appendix C6). The subjects were seated in a chair with their head placed on a chin/forehead rest, 57 cm from the computer monitor, with headphones placed on their ears. Furthermore, a head mounted eye tracker was placed on their head.

Each trial began with an asterisk at the center of the screen, on which they were asked to fixate and when they were ready to begin they pressed the yellow key on the button box. Shortly after, the set of six pictures of objects appeared, and the center asterisk was replaced by a green dot. Green indicated that subjects were free to move their eyes across the screen. The pictures were shown for 6000 ms and then the central

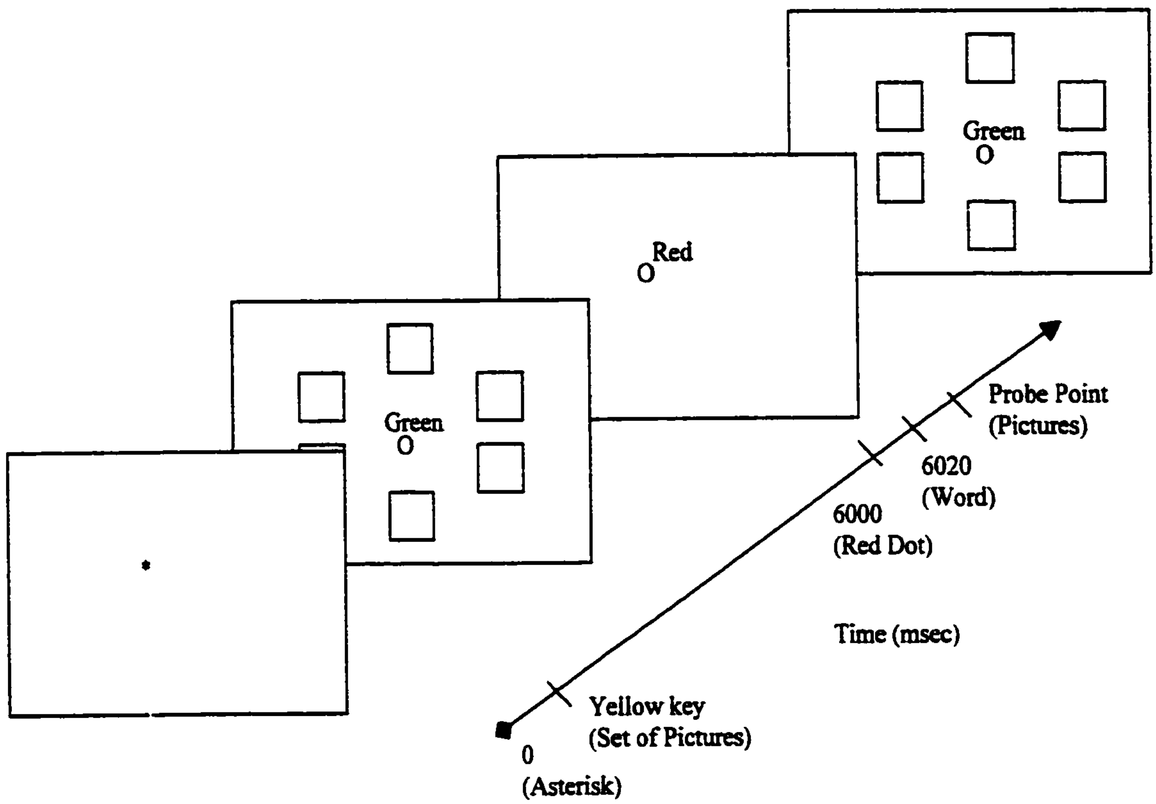


Figure 8. Schematic representation of a sequence of stimuli in Experiment 2.

dot turned red. Red indicated that subjects were required to fixate on the dot and not move their eyes. Shortly after, the target word was uttered through the headphones. At three probe points (onset, offset, offset+200 ms of the word) the pictures appeared once more, in the same order, and the dot turned green. Subjects' task was to move their eyes to the picture of the object they just heard and press the green key on the button box. This moved the subjects to the next trial. The target object was always present and randomly positioned. Each subject received the 24 words once, eight at each probe point. The PC computer which communicated with the Macintosh G4 recorded saccade onset times and pixel coordinates of saccades and fixations.

Results and Discussion

For each subject saccade onsets shorter than or greater than two standard deviations (SD) from the mean were replaced with the value of two SD above or below. Trials on which subjects were not at fixation at the onset of the green dot were excluded. These two criteria excluded 8.80% of the trials. Results are shown in Figure 9 for words presented in isolation at each probe point condition. Each point represents the average time to initiate a saccade to the target object, averaged across all subjects. Inspection of Figure 9 shows that as the delay between the onset of the name of the target object and the onset of the green dot increased the time to initiate a saccade to the target object decreased. As shown in Figure 10, we also examined the time to initiate a saccade to the target object per item. Inspection of Figure 10 shows that as the delay between the onset of the word and the green dot increased the time to initiate a saccade to the target object decreased. The data were analyzed using two one-way repeated measures ANOVA, with an alpha level of .05 significance (see Appendix D, Table 2 & 3). As expected, the

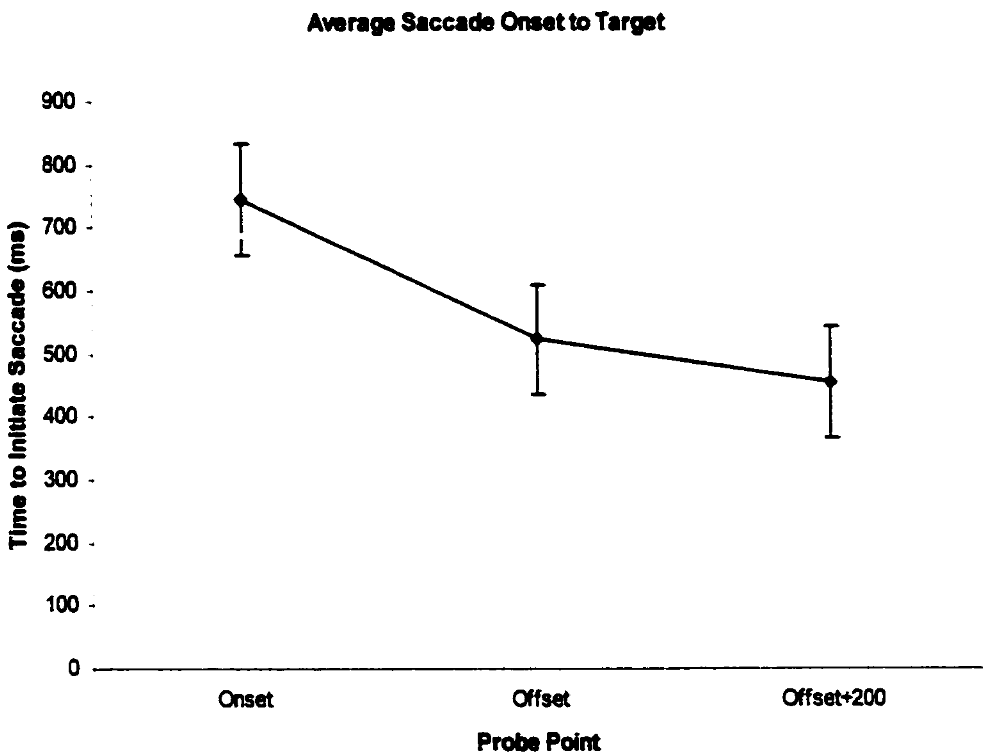


Figure 9. Average saccade onset to the target object at each probe point, averaged across subjects, for words presented in isolation in a memory matching task.

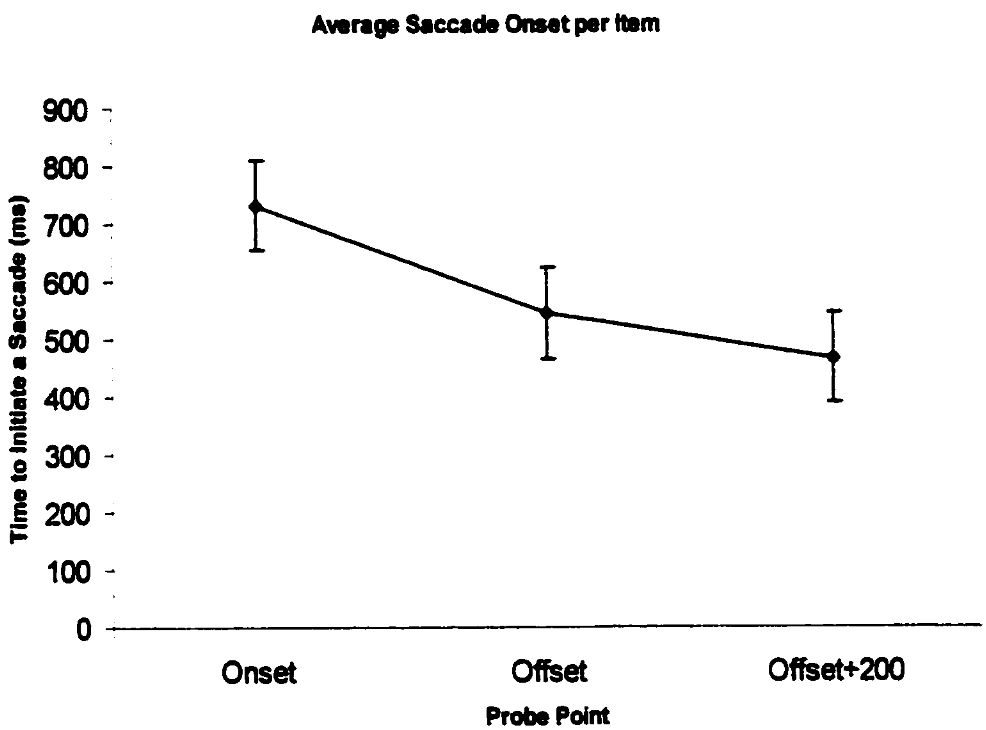


Figure 10. Average saccade onset per item, averaged across subjects, for words presented in isolation in a memory matching task

results were significant by subject and by item, $\underline{F1}(2,8) = 20.37$, $\underline{p} <.0001$, $\underline{F2}(2, 23) = 23.89$, $\underline{p} <.0001$, for probe points. I then conducted Tukey post-hoc pairwise comparisons (see Appendix D, Table 3 & 4), and it demonstrated that this difference lay between the onset and offset probe points, and the onset and offset+200msec probe point conditions.

Results are shown in Figure11 for words presented in isolation at each probe point condition, however only for saccades to the target object at the first saccade. Each point represents the time to initiate a saccade to the target object at the first saccade, averaged across all subjects. Figure12, on the other hand, shows the percentage of correct responses to the target object at the first saccade. Each point represents the percent correct responses to the target object at the first saccade, averaged across all subjects. Inspection of Figure 11 shows that as the delay between the onset of the word and the green dot increased the time to initiate a saccade to the target object decreased. While Figure 12 shows that as the delay increased the amount of correct responses increased. We analyzed the data using two one-way repeated measures ANOVA (see Appendix D, Table 4 & 5). There was a statistically significant difference between probe points for time to initiate a saccade, $\underline{F}(2,4) = 14.87$, $\underline{p} = .002$ and a strong trend in percent correct responses, $\underline{F}(2,8) = 3.56$, $\underline{p} = .0527$. We then conducted Tukey post-hoc pairwise comparisons (see Appendix D, Table 4), and it demonstrated that this difference lay between the onset and offset+200 ms probe point conditions.

Due to the large number of errors at the first saccade (70.37%), we inspected the percentage of errors in the first saccade for each type of competitor, as shown in Figure

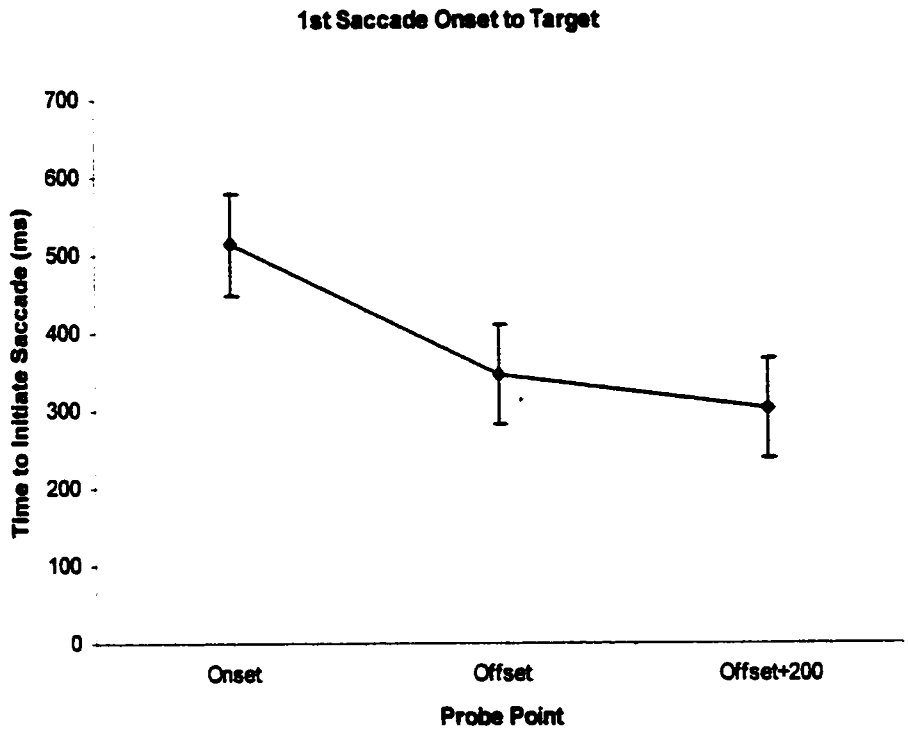


Figure 11. First saccade onset to the target object at each probe point, averaged across subjects, for words presented in isolation in a memory matching task.

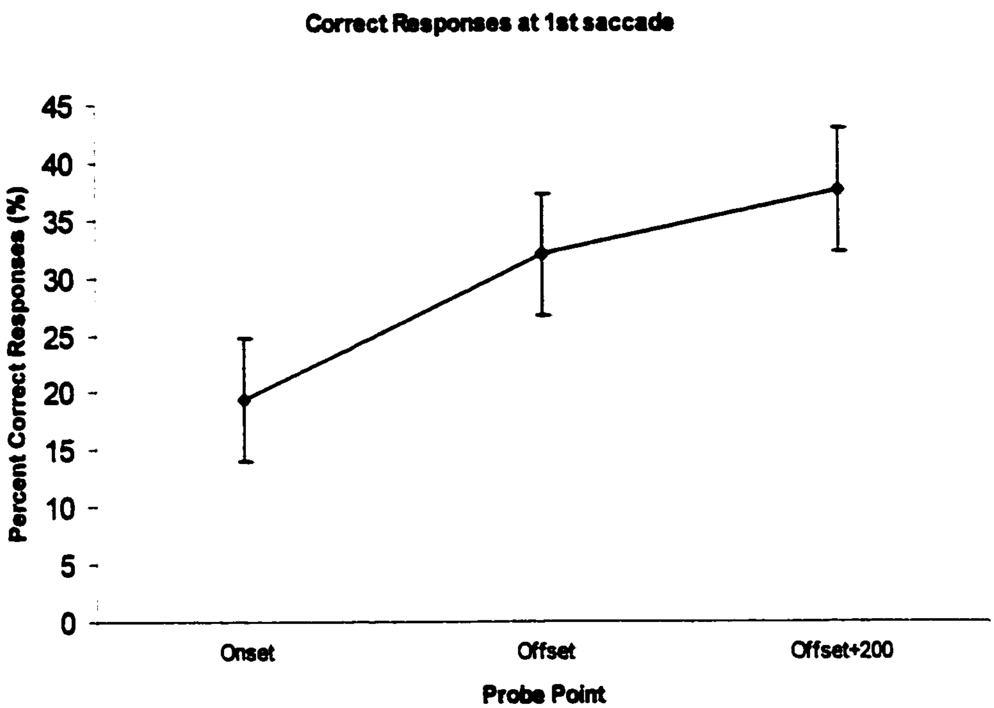


Figure 12. Percent correct responses at first saccade, averaged across subjects, for words presented in isolations in a memory matching task.

13. Each point represents the percent of responses to each competitor at the first saccade, averaged across subjects. The data were analyzed using a two-way repeated measures ANOVA (see Appendix D, Table 6). There was no statistically significant difference between the five types of competitors, $\underline{F}$ (4,8) = 1.34, $\underline{p}$ = .277. There was, however, a statistically significant interaction between the type of competitor and probe point conditions, $\underline{F}$(8,8) = 2.54, $\underline{p}$ = .0181. It appears that the phonological competitor was stronger in the onset condition, while in the offset+200 ms condition the semantic competitor was the strongest, compared to the other competitors.

Finally, as shown in Figure 14, we examined the time to initiate the 1st saccade, regardless of whether it was to the target object. Each point represents the time to initiate a saccade to an object, averaged across subjects. Inspection of Figure 14 demonstrates that subjects tended to wait longer before initiating a saccade to an object in the earlier probe point conditions. The data were analyzed using a one-way repeated measures ANOVA (see Appendix D, Table 7). There was a statistically significant difference between probe points, $\underline{F}$(2,53) = 13.27, $\underline{p}$ = <.0001. We then conducted Tukey post-hoc pairwise comparisons, and it demonstrated that this difference lay between the onset and offset probe points, as well as the onset and offset+200 ms probe point conditions (see Appendix D, Table 7).

In summary, there was quite a large decrease in saccade onset time between the onset and offset probe points and then it leveled off, for average saccade onset, correct first saccades, and per item analysis. This suggests that the processing and programming of the target object was completed some time before the offset of the word. As well subjects waited longer to initiate the 1st saccade (regardless of whether it was to the target

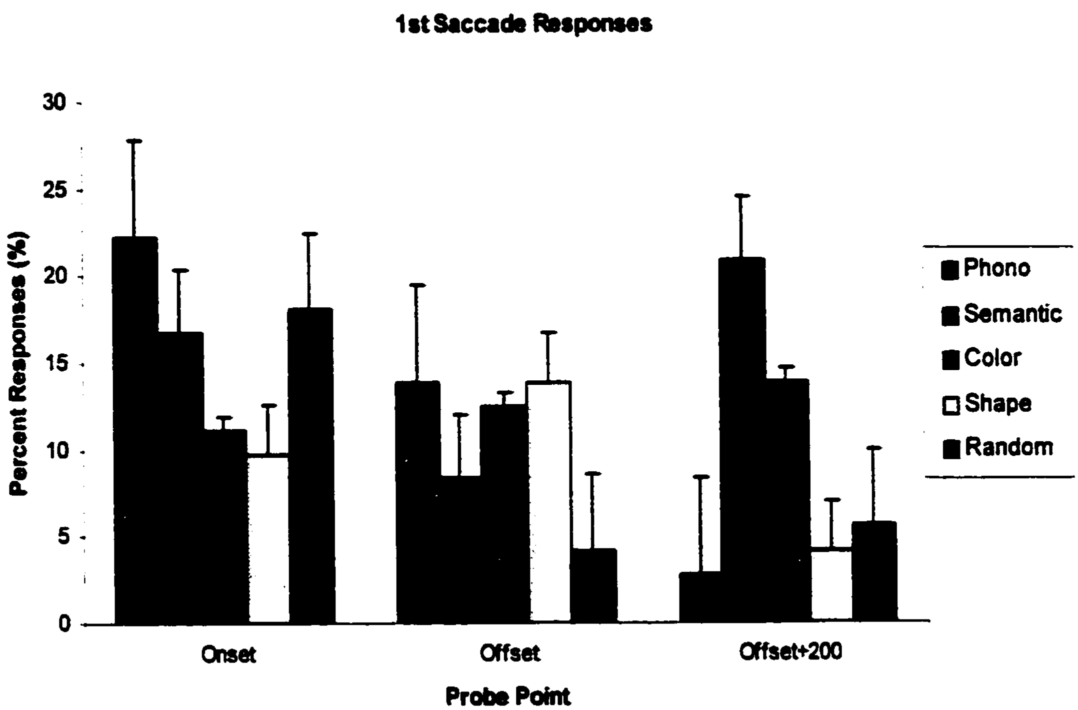


Figure 13. Percent responses at first saccade to each competitor, averaged across subjects, for words presented in isolations in a memory matching task.

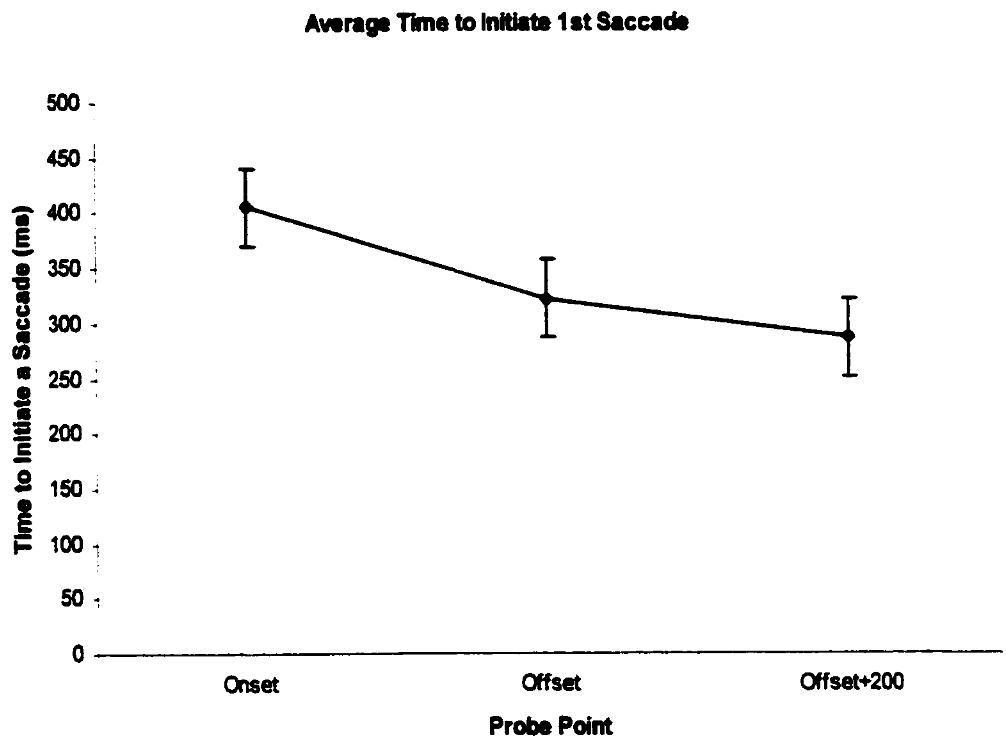


Figure 14. First saccade onset to an object, averaged across subjects, for words presented in isolation in a memory matching task.

object) in the onset probe point conditions, indicating that subjects were waiting for the word to unfold before beginning their search. For the number of incorrect saccades there did not appear to be any difference between competitor types. There was, however, a significant interaction, whereby phonological competitors were stronger in the onset probe conditions, while semantic competitors were a stronger competitor in the offset+200 ms probe point conditions. The measurements of saccade onsets to the target noun in the sentence experiment (Experiment 4) will be subtracted from the saccade time for the words in isolation in order to obtain a pure measurement of verb effects in the sentences.

Experiment 3

In this experiment we used the same stimuli and procedures as in Experiment 2 with the exception that we changed the memory matching task to a visual search task. We attempted to observe whether all saccade onset times obtained in Experiment 2 were due to memory effects or pure search effects.

Method

Subjects. Nine Concordia Psychology undergraduate students participated in this experiment. They participated either for course credit or for $5.00. All were native speakers of English and had normal or corrected-to-normal vision (20/20 Snellen).

Apparatus and Stimuli. The apparatus and stimuli used in this experiment were the same as in Expeirment 2.

Procedure. The procedure was the same as in Experiment 2 except that the matching task was replaced by a visual search task. To accomplish this we removed the initial presentation of the six pictures of objects that subjects were previously allowed to scan freely. After completion of the consent form (see Appendix B4), subjects were presented the instructions on the screen (see Appendix C7). The experimenter answered any questions they may have had. After the practice trials, as a reminder of the task at hand, subjects received a shorter version of the instructions (see Appendix C8). Each trial started with an asterisk. When the subjects were ready to begin they pressed the yellow key on the button box. The asterisk was then replaced with a red dot which subjects were asked to fixate. After a delay of 20 ms a word (the name of the target object) was uttered through the headphones. At one of three probe points (onset, offset, offset+200 ms of the word) the pictures of objects appeared on the screen and the dot turned green (see Figure 15 for a schematic representation). The subjects' task was to find the picture of the word just heard as quickly as possible. When fixated on the target object they pressed the green key on the button box, which brought them to the next trial. The PC computer recorded saccade onset times and pixel coordinates of saccades and fixations.

Results and Discussion

For each subject saccade onsets shorter than or greater than two standard deviations (SD) from the mean were replaced with the value of two SD above or below. Trials whereby subjects were not at fixation at the onset of the green dot were excluded. These criteria excluded 6.02% of the trials. Results are shown in Figure 16 for words presented in isolation at each probe point. Each point represents the average time to initiate a saccade to the target object,

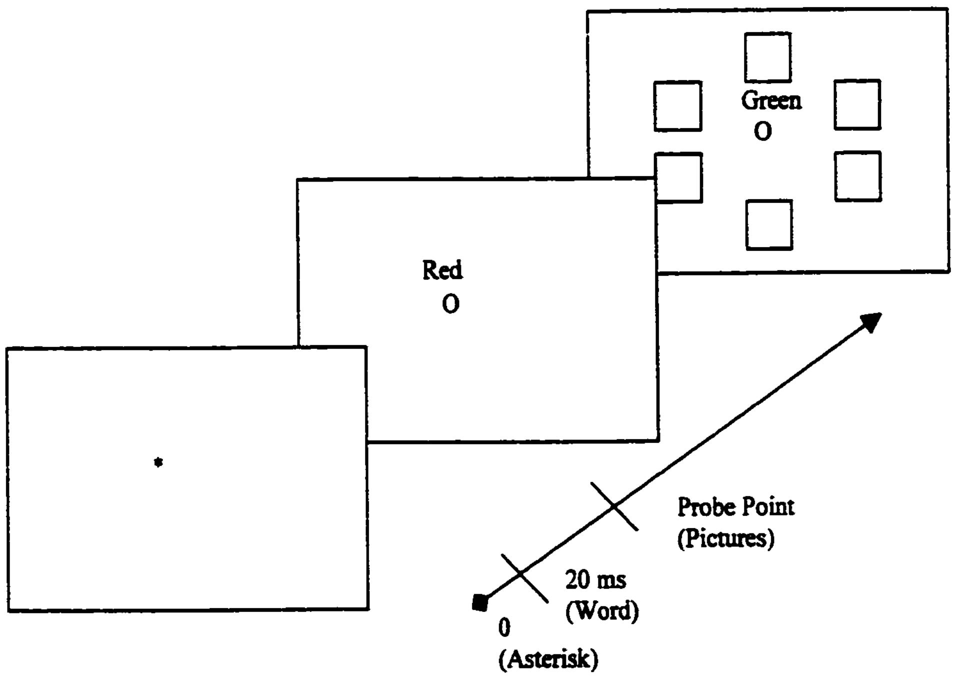


Figure 15. Schematic representation of a sequence of stimuli in Experiment 3.

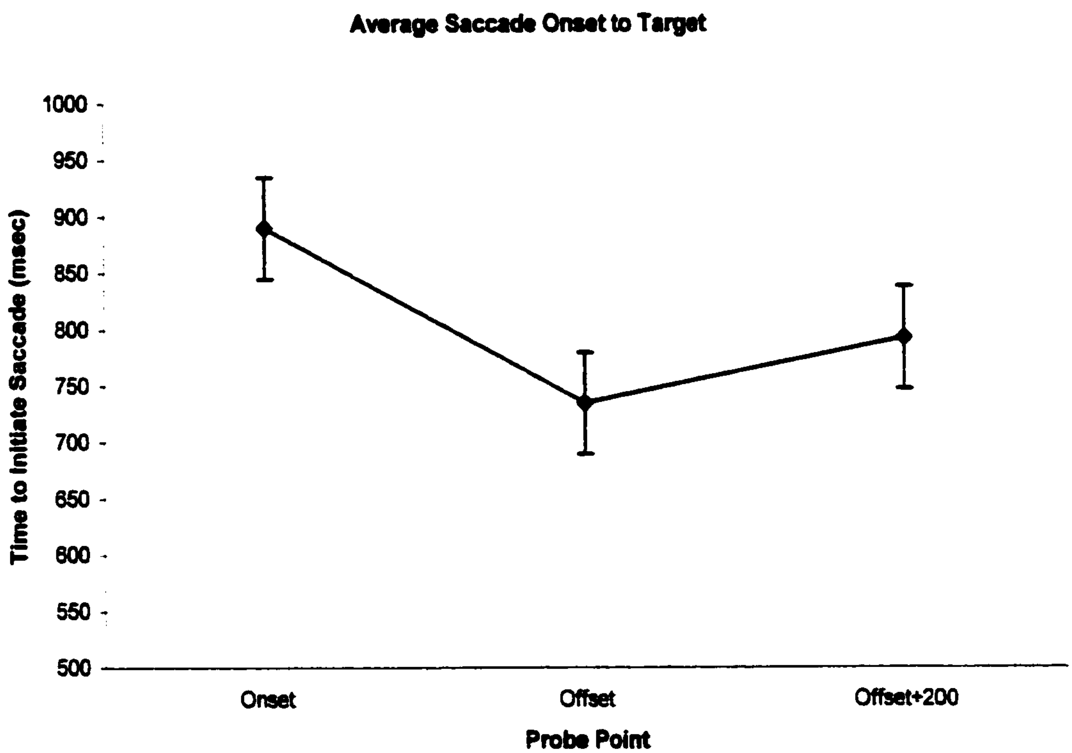


Figure 16. Average saccade onset to the target object at each probe point, averaged across subjects, for words presented in isolation in a visual search task.

averaged across all subjects. Inspection of Figure 16 shows that there was quite a large decrease in saccade onset time between the onset and offset probe points and then it leveled off. This suggests that the processing and programming of the target object was completed some time before the offset of the word. As shown in Figure 17, we examined the time to initiate a saccade to the target object per item. Inspection of Figure 17 shows that there was a slight decrease in saccade onset time between the onset and offset probe point conditions and then it leveled off. The data were analyzed using two one-way repeated measures ANOVA, with an alpha level of .05 significant (see Appendix D, Table 8 & 9). As expected, the results were statistically significant by subject and by item, $F1(2,8) = 4.16$, $p = .035$, $F2(2,23) = 6.76$, $p = .0027$. We then conducted Tukey post-hoc pairwise comparisons (see Appendix D, Table 8 & 9), and it demonstrated that this difference was not statistically significant in the by subjects analysis, but in the by items analysis the difference lay between the onset and offset probe point conditions.

Results are shown in Figure 18 for words presented in isolation at each probe point, however only for correct saccades to the target object at the first saccade. Each point represents the time to initiate a saccade to the target object at the first saccade, averaged across all subjects. Figure 19 shows the percentage of correct responses to the target object at the first saccade. Each point represents the percent correct responses to the target object at the first saccade, averaged across all subjects. Inspection of Figure 19 shows that there was a slight decrease in saccade onset time between the onset and offset probe point conditions and then it leveled off, while Figure 19 shows that as the delay

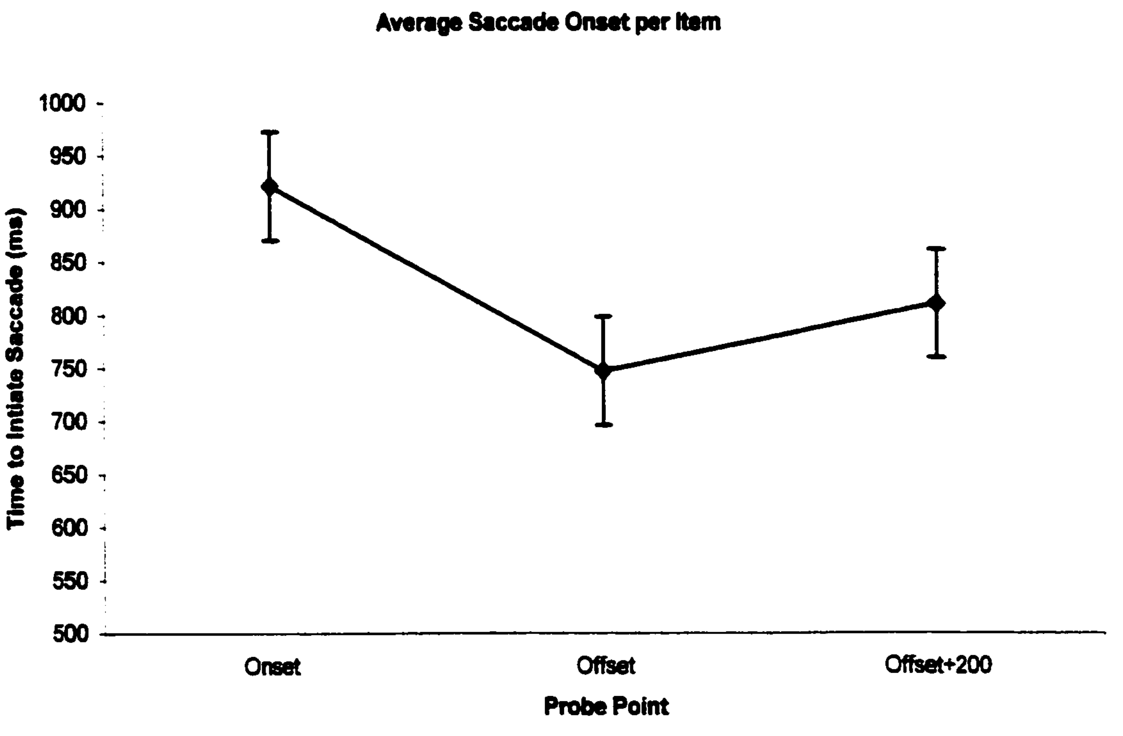


Figure 17. Average saccade onset per item, averaged across subjects, for words presented in isolation in a visual search task.

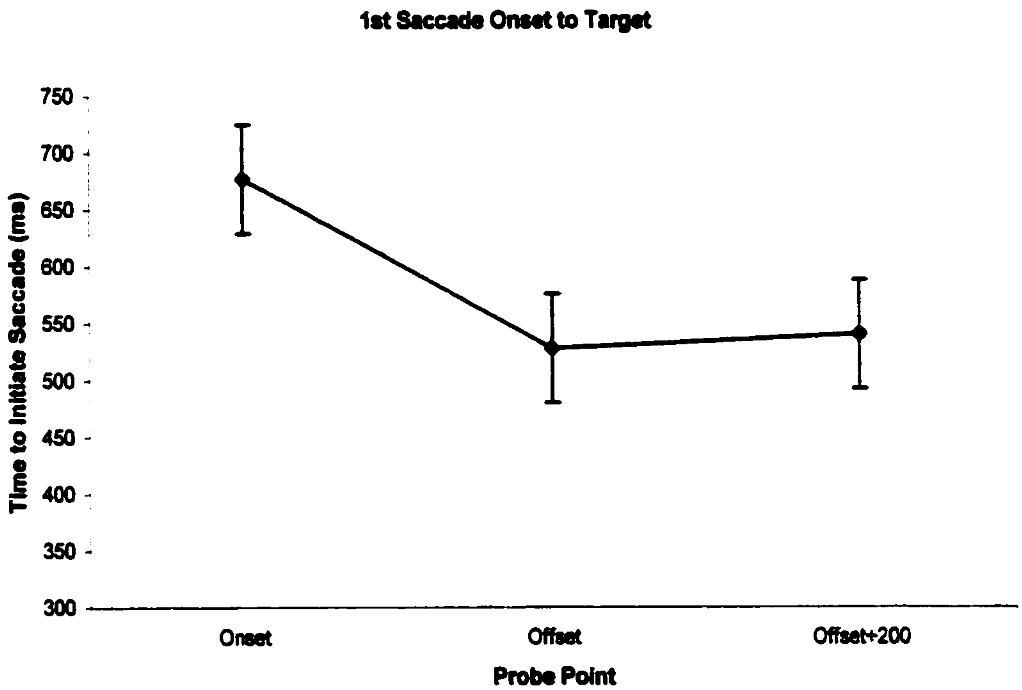


Figure 18. First saccade onset to initiate a saccade to the target object at each probe point, averaged across subjects, for words presented in isolation in a visual search task.

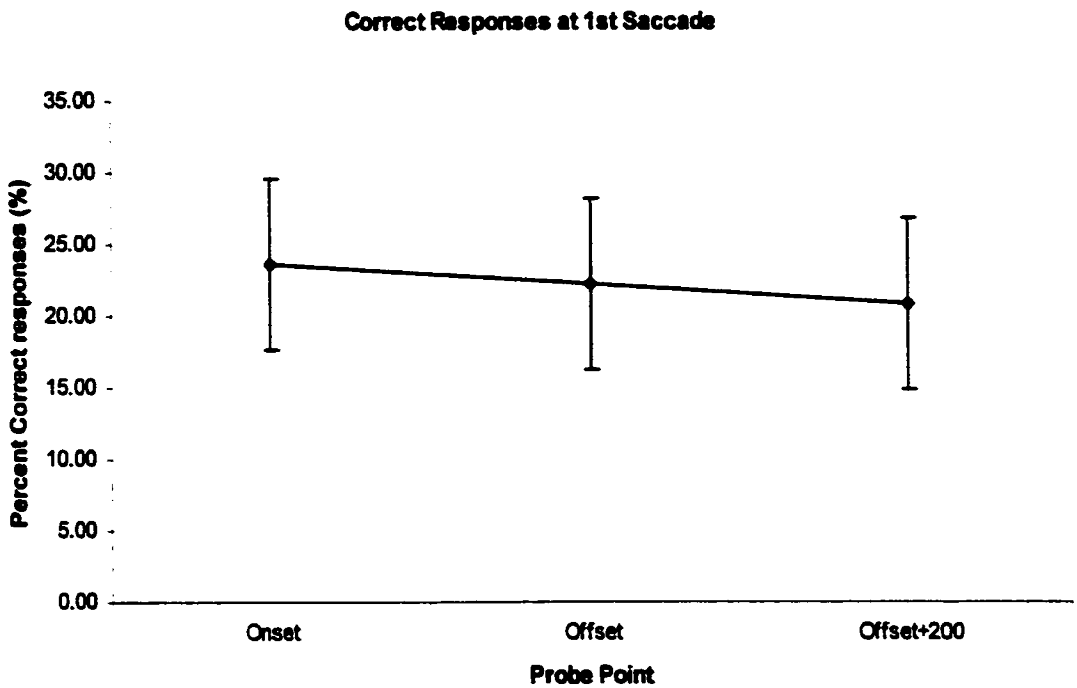


Figure 19. Percent correct responses at first saccade, averaged across subjects, for words presented in isolation in a visual search task.

between the onset of the word and the green dot increased the amount of correct responses remained approximately the same. We analyzed the data using two one-way repeated measures ANOVA (see Appendix D, Table 10 and 11). There was no statistically significant difference between probe points for time to initiate a saccade to target object at the first saccade, $\underline{F}(2, 4) = 3.18$, $\underline{p} = .0965$ and percent correct responses, $\underline{F}(2,8) = 0.073$, $\underline{p} = .930$.

Due to the large number of errors for the first saccade (77.78 %), we inspected the percentage of errors in the first saccade for each type of competitor, as shown in Figure 20. Each point represents the percent of responses to each competitor at the first saccade, averaged across subjects. The data were analyzed using a two-way repeated measures ANOVA (see Appendix D, Table 12). There was no statistically significant difference between the five types of competitors, $\underline{F}(4,8) = 0.120$, $\underline{p} = .975$. There was, however, a statistically significant interaction between the type of competitor and the probe point conditions, $\underline{F}(8,8) = 2.79$, $\underline{p} = .0103$. It appears that the phonological competitor was strongest at the onset probe conditions, the shape competitor at the offset, and the color competitor was the strongest at the offset+200 ms probe point conditions.

Furthermore, as shown in Figure 21, we examined the time to initiate the 1st saccade to an object, regardless of whether it was the target object. Each point represents the time to initiate the 1st saccade, averaged across subjects. Inspection of Figure 21 shows that there was a decrease in waiting time to initiate a saccade between the onset and offset probe point conditions and then it leveled off. We analyzed the data using a one-way repeated measures ANOVA (see Appendix D, Table 13). There was a

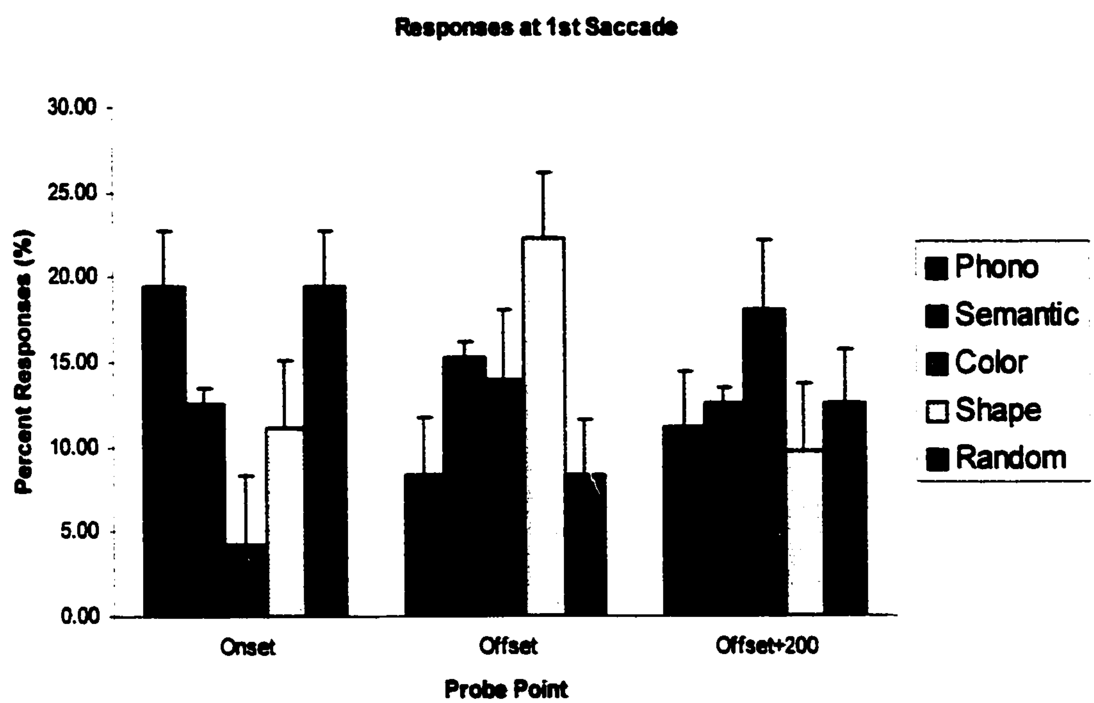


Figure 20. Percent responses at first saccade to each competitor, averaged across subjects, for words presented in isolation in a visual search task.

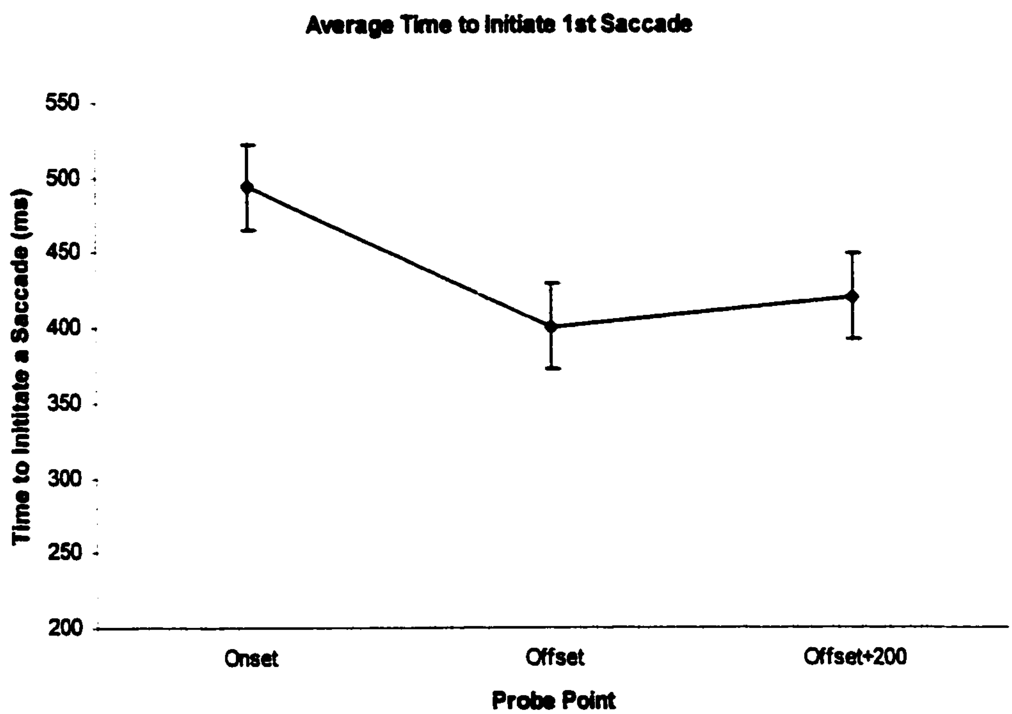


Figure 21. First saccade onset to an object, averaged across subjects, for words presented in isolation in a visual search task.

statistically significant difference between probe points, $F(2,60) = 6.99$, $p = .0013$. We then conducted Tukey post-hoc pairwise comparisons (see Appendix D, Table 13), and it demonstrated that this difference lay between the onset and offset probe points, as well as the onset and offset+200 ms probe point conditions.

As a final analysis, we compared subjects' performance on each task (memory matching and visual search tasks). Average time to initiate a saccade results are shown in Figure 22 comparing words presented using each task. Each point in Figure 22 represents the average time to initiate a saccade to the target object, at each probe point, across tasks and averaged across subjects. Inspection of Figure 22 shows that subjects had faster average saccade onset times to the target object in the memory matching task and that this difference increased as the delay between the onset of the word and the green dot increased. We analyzed the results using a two-way repeated measures ANOVA (see Appendix D, Table 14). There was a statistically significant difference between the two tasks for the average saccade onset, $F(1,8) = 22.24$, $p = .0015$, probe point, $F(2,8) = 18.28$, $p < .0001$, and a statistically significant interaction between tasks and probe point, $F(2,8) = 6.67$, $p = .0078$.

As shown in Figure 23, a similar analysis was conducted for correct saccades to the target object at the first saccade. Each point represents the time to initiate a saccade to the target object at the first saccade, across tasks, averaged across all subjects. Figure 24 shows the percentage of correct responses to the target object at the first saccade. Each point represents the percent correct responses to the target object at the first saccade, across tasks, averaged across all subjects. Inspection of Figure 23 shows that

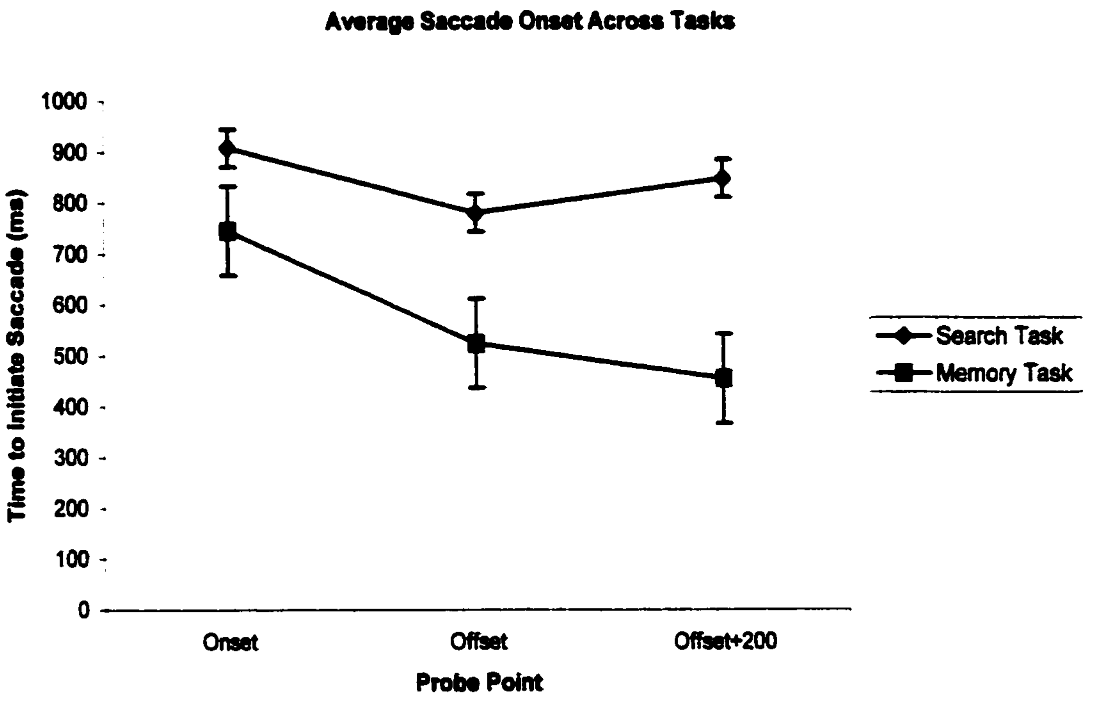


Figure 22. Average saccade onset to target object at each probe point, across tasks, averaged across subjects, for words presented in isolation.

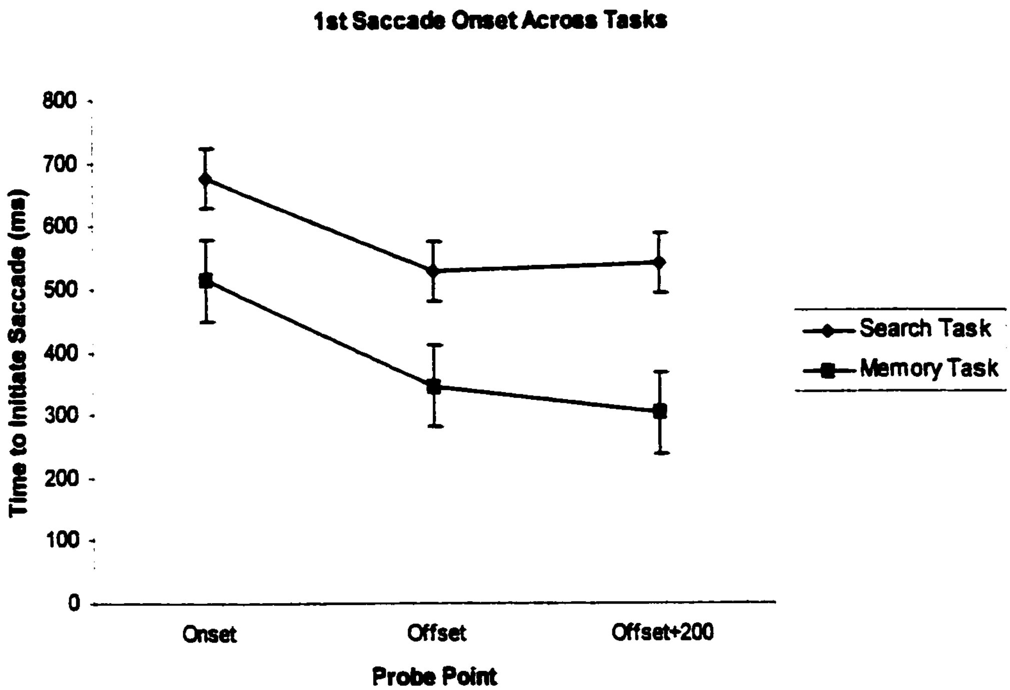


Figure 23. First saccade onset to the target object at each probe point, across tasks, averaged across subjects, for words presented in isolation.

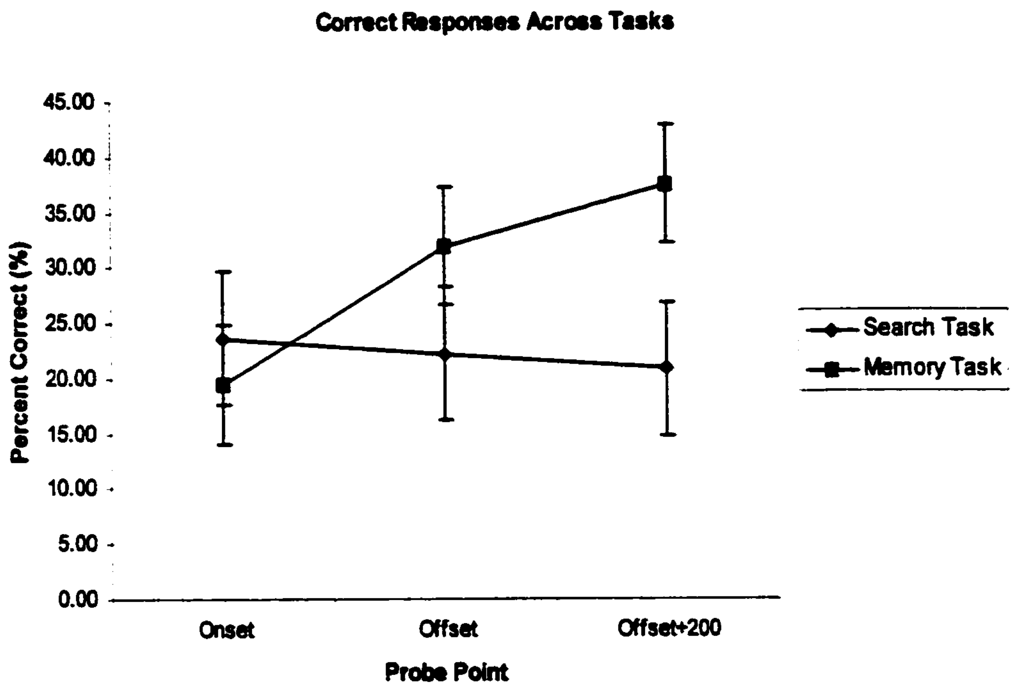


Figure 24. Percent correct responses at first saccade, across tasks, averaged across subjects, for words presented in isolation.

subjects had faster saccade onset time in the memory task, while Figure 24 shows that subjects made more correct responses in the memory matching task, and that these differences increased as the delay between the onset and the green dot increased. I analyzed the data using two one-way repeated measures ANOVA (see Appendix D, Table 15 and 16). There was a statistically significant difference between the two tasks for first saccade, $\underline{F}(1,4) = 14.65$, $\underline{p} = .0187$, but not of percent correct responses, $\underline{F}(1,8) = 2.86$, $\underline{p} = .1293$.

In summary, as in Experiment 2, there was quite a large decrease in saccade onset time between the onset and offset probe points and then it leveled off, for average saccade onset time, correct first saccades, and per item analysis. This suggests that the processing and programming of the target object was completed some time before the offset of the word. As well subjects waited longer to initiate the 1st saccade (regardless of whether it was to the target object) in the onset probe point conditions, indicating that subjects were waiting for the word to unfold before beginning their search. For the number of incorrect saccades there did not appear to be any difference between competitor types. There was, however, a significant interaction, whereby phonological competitor was strongest at the onset probe conditions, shape competitor at the offset, and color competitor was the strongest at the offset+200 ms probe point conditions. Finally there was a significant difference between subjects' performance on the memory matching task and the visual search task, more specifically subjects had quicker saccade onset times in the memory matching task, suggesting that the results in Experiment 2 were due to memory effects.

Experiment 4

In this experiment we used the information from Experiment 2 to track the time course of access to verb-complement information. In order to obtain this pure measurement of verb effects, the measurements of saccade onsets to the target noun in this sentence experiment will be subtracted from the saccade onsets to the target noun when presented in isolation (Experiment 2). Furthermore, two sets of sentences were contrasted, a highly constraining causative construction in which there was a close conceptual relation between the verb and its direct object, and a neutral construction, with a transitive perception verb. This study was a basic three factors repeated measures design, the factors being: probe point (time delay between the presentation of the noun in the sentence and the onset of the pictures of objects, three levels), type of objects (six levels, noun, and shape, color, phonological, semantic and random competitors), and class of verb (2 levels, causative and perception).

Method

Subjects. 18 Concordia Psychology undergraduate students participated in this experiment. They participated either for course credit or for $5.00. All were native speakers of English and had normal or corrected-to-normal vision (20/20 Snellen).

Apparatus and Stimuli. The apparatus and stimuli used in this experiment were the same as in Experiment 2 with the exception of the target object (noun) being presented within a sentence. The sentences included a subject, verb and noun (e.g., The woman burned the candle). The verbs were either causative, which had a close conceptual relation with its direct object (e.g., burned-candle) or transitive perceptual (e.g., admired-candle). Fillers were included in which the direct object (noun) referred to in the sentence was not present and whereby the onset of the pictures of objects was not near the advent of the noun. This was to allow for a two-alternative forced choice task.

Procedure. The procedure in this experiment was the same as in Experiment 2 with the exception of the noun being presented within a sentence, with its related conceptual verb, and subjects were asked to make a yes/no decision of whether the object just heard was present. If the object was present, subjects fixated the object and pressed the green key, if it was not present they pressed the red key on the button box. The experiment was divided into three sessions, eye tracker calibration, three practice trials and 60 experimental trials and lasted approximately 20 min. The experimental trials were further divided into 12 trials with causative verbs where the target object was present; 12 trials with perceptual verbs where the target object was present; 24 trials with direct object not present; six trials with random onset of pictures where the target object was present; six trials with random onset of pictures where the target object was not present. These 36 fillers were to prevent subjects from anticipating the correct response and the onset of the pictures of objects. Each subject saw only one of the two possible versions (i.e. causative or perception) of the spoken description that could accompany the display. After the completion of the consent form (see Appendix B5), subjects were presented the instructions on the screen (see Appendix C9). I then answered any questions they may have had. After the practice trials, as a reminder of the task at hand, subjects received a shorter version of the instructions (see Appendix C10). The three probe points remained the same as in Experiment 2 (onset, offset and offset+200 ms of the noun).

Results and Discussion

For each subject saccade onsets shorter than or greater than two standard deviations (SD) from the mean were replaced with the value of two SD above or below. Trials whereby subjects were not at fixation at the onset of the green dot were excluded. These criteria excluded 13.89% of the trials. Results are shown in Figure 25 for target objects (nouns) presented in a sentence at each probe point for each verb type condition. Each point represents the average time to initiate a saccade to the target object, averaged across all subjects. Inspection of Figure 25 shows that as the delay between the onset of the noun in the sentence and the green dot increased, the overall time to initiate a saccade to the target object decreased regardless of the type of verb. There, however, appears to be no difference between the two classes of verbs in terms of average saccade onset to the target object. As shown in Figure 26, we examined the time to initiate a saccade to the target object per item. Inspection of Figure 26 shows that there was a slight decrease in time to initiate a saccade to the target object as the delay between the onset of the sentence and the green dot increased. There also appears to be no difference between the two classes of verbs. We analyzed the data using two two-way repeated measures ANOVA (see Appendix D, Table 17 & 18). There was a statistically significant effect of probe point, $F1(2,16) = 6.80$, $p = .0035$, $F2(2,23) = 5.40$, $p = .0078$, however there was no statistically significant effect of verb type, $F1(1,16) = 0.002$, $p = .9622$, $F2(1,23) = 0.145$, $p = .7073$. Tukey post-hoc pairwise comparisons illustrated that this difference lay between the onset and offset+200 ms probe point conditions for F1 and between the onset and offset probe points, and onset and offset+200 ms probe point conditions forF2 (see Appendix D, Table 17 & 18).

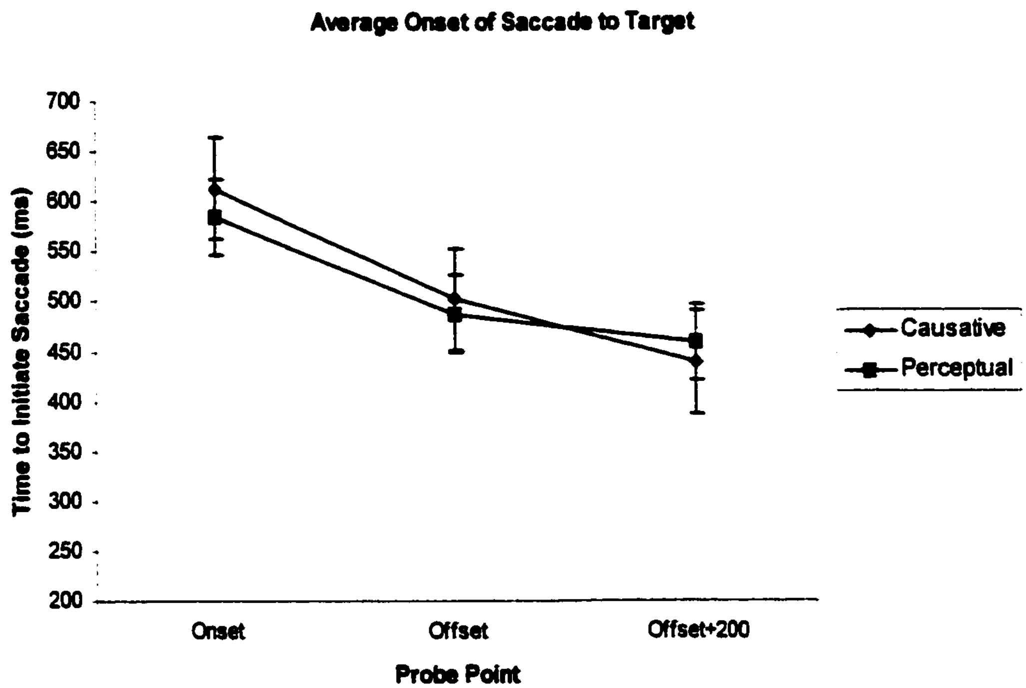


Figure 25. Average saccade onset to the target object within a sentence for each verb type, at each probe point, averaged across subjects in a memory matching task.

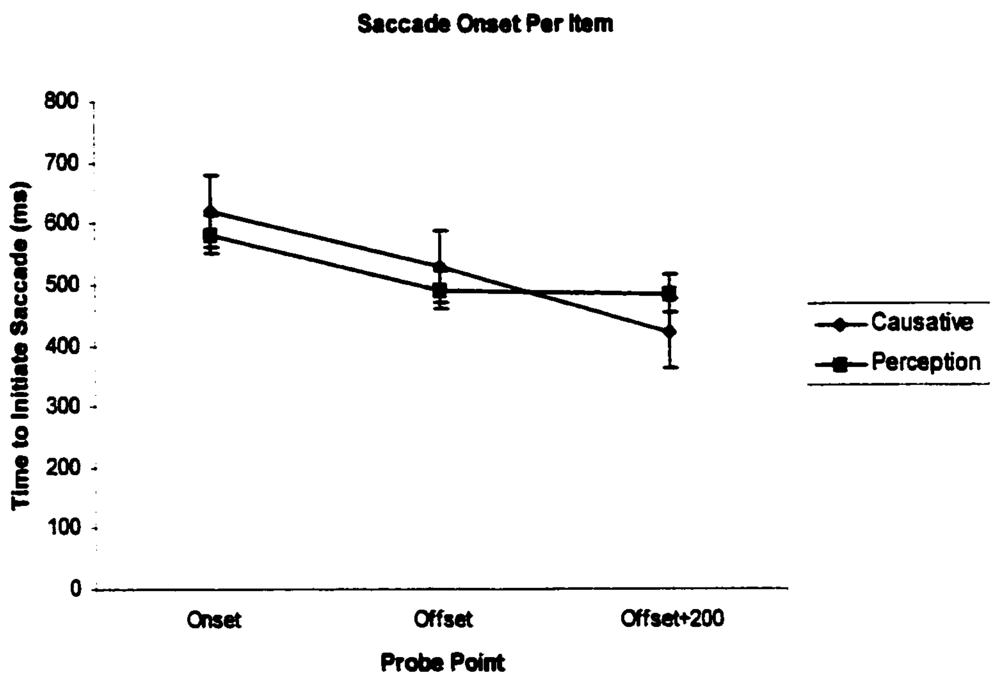


Figure 26. Average saccade onset per item, for each verb type, averaged across subjects, in a memory matching task.

Results are shown in Figure 27 for target objects (nouns) presented in a sentence at each probe point for each verb type, however only for the first correct saccade. Each point represents the time to initiate a saccade to the target object at the first saccade, averaged across subjects. Figure 28 shows the percentage of correct responses to the target object at the first saccade. Each point represents the percent correct responses to the target object at the first saccade, averaged across all subjects. Inspection of Figure 28 shows that as the delay between the onset of the noun in the sentence and the green dot increased, the first saccade time to initiate a saccade to the target object decreased. There, however, appears to be no difference between the two classes of verbs in terms of saccade onset time to the target object for the first saccade. Figure 28 shows that there was an advantage of the perceptual verbs compared to the causative verbs in terms of percent correct responses for the offset and offset+200ms conditions. This suggests a possible speed/accuracy tradeoff. We analyzed the data using two two-way repeated measures ANOVA (see Appendix D, Table 19 and 20). There was no statistically significant effect of probe point, $F(2,4) = 3.23$, $p = .0936$, or verb type, $F(1,4) = 0.372$, $p = .5748$, for saccade onset time at first saccade. For correct responses there was no effect of probe point, $F(2,17) = 2.095$, $p = .1387$, and verb type, $F(1,17) = 1.42$, $p = .2492$.

Due to the large number of errors at the first saccade (72.22 %), we inspected the percentage of errors in the first saccade for each type of competitor, as shown in Figure 29 for causative verbs and Figure 30 for perception verbs. Each point represents the percentage of responses to each competitor at the first saccade, averaged across subjects. The data were analyzed using two two-way repeated measures ANOVA (see Appendix D, Table 21 and 22). For the causative verb type there was no significant difference

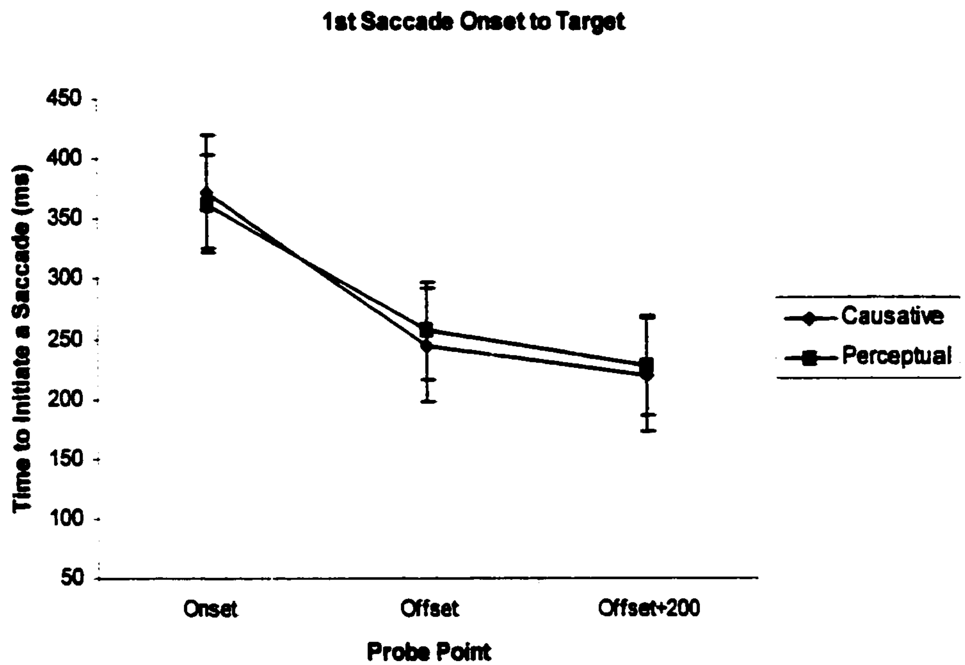


Figure 27. First saccade onset to initiate a saccade to the target object for each verb type, at each probe point, averaged across subjects, for words presented within a sentence in a memory matching task.

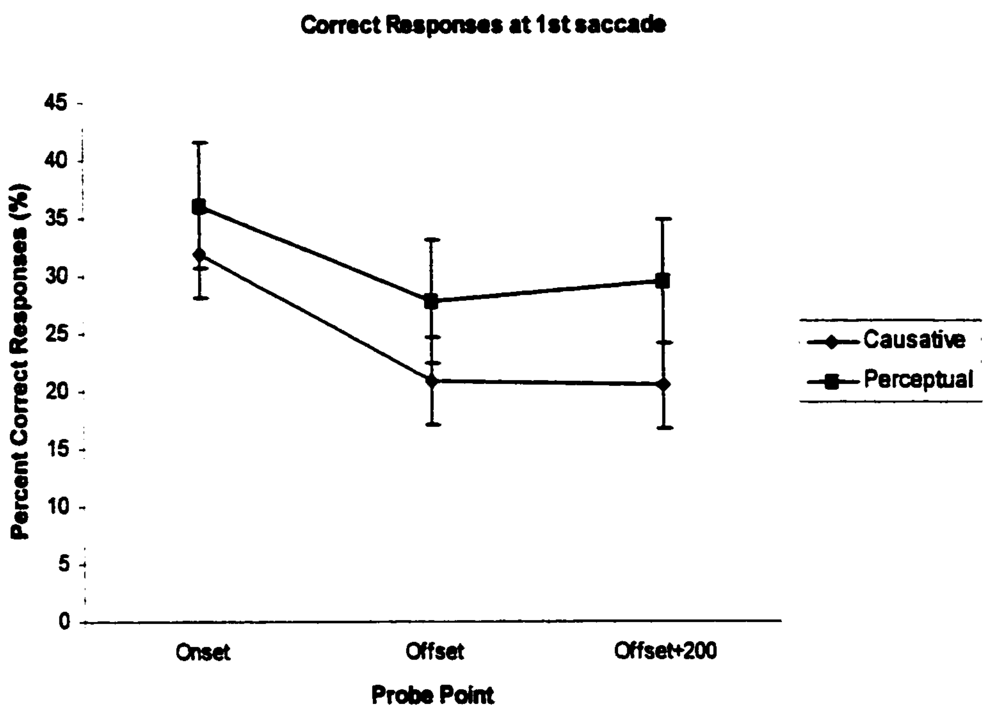


Figure 28. Percent correct responses at first saccade, for each verb type, at each probe point, averaged across subjects, for words presented within a sentence in a memory matching task.

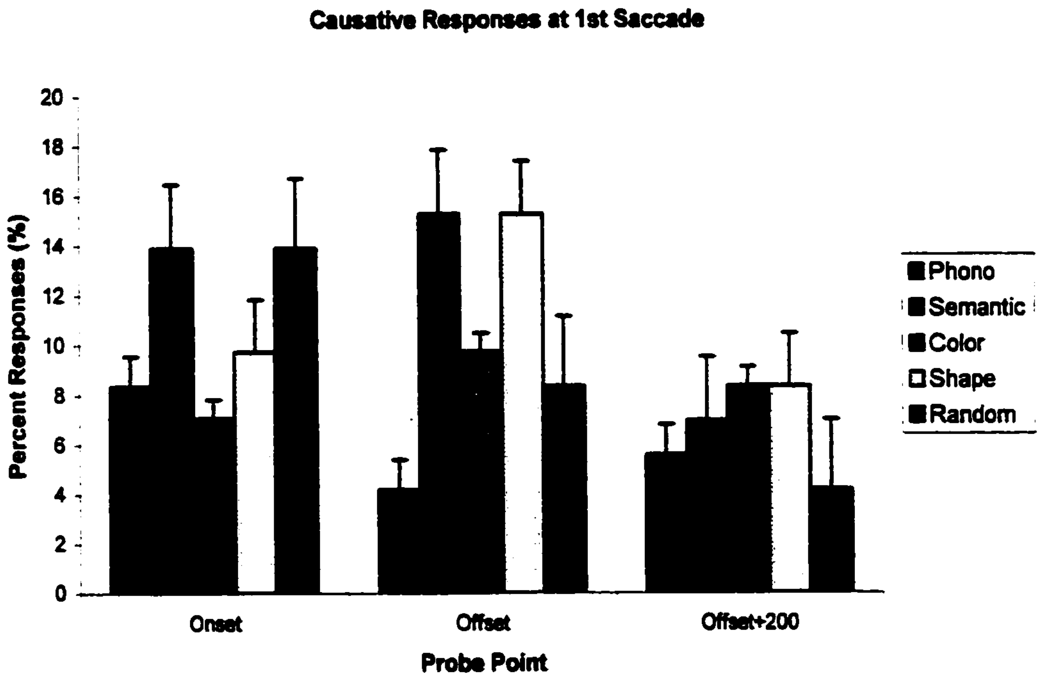


Figure 29. Percent responses to each type of competitor, within a sentence for causative verb type, at each probe point, averaged across subjects in a memory matching task.

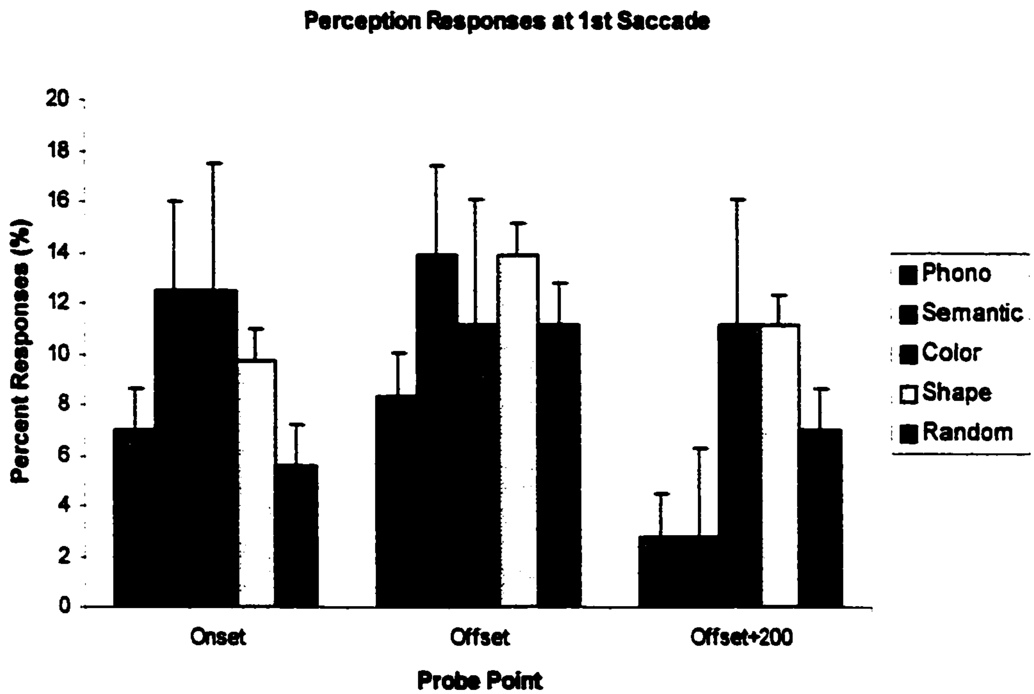


Figure 30. Percent responses to each competitor type, within a sentence for perception verb type, at each probe point, averaged across subjects in a memory matching task.

between competitors, $F(4,17) = 1.78$, $p = .142$. For the perception verb type there was no statistically significant difference between competitors, $F(4,17) = 1.63$, $p = .178$.

Furthermore, as shown in Figure 31, we examined the time to initiate the first saccade to an object, regardless of whether it was the target object. Each point represents the time to initiate the first saccade, averaged across subjects. Inspection of Figure 31 shows that there was a decrease in waiting time to initiate a saccade as the delay between the onset of the sentence and the green dot increased, however there appears to be a slight advantage for the causative verb conditions. I analyzed the data using a two-way repeated measures ANOVA (see Appendix D, Table 23). There was a statistically significant difference between probe points, $F(2,37) = 16.42$, $p = <.0001$, and verb types, $F(1,37) = 11.50$, $p = .0017$. I then conducted Tukey post-hoc pairwise comparisons (see Appendix D, Table 23), and it demonstrated that this difference lay between the onset and offset probe points, and onset and offset+200 ms probe point conditions.

Finally, as shown in Figure 32, I obtained the pure verb effect values by taking the measurements of saccade onsets to the target noun when presented in isolation and subtracted from it the saccade onsets to the target noun in the sentence experiment. Each point represents the difference between the average time to initiate a saccade to the target object for each type of presentation (in isolation vs. in a sentence), averaged across subjects. Inspection of Figure 32 shows that the values are nearly all positive indicating that subjects performed more quickly when the noun was presented within a sentence than in isolation, and that this difference decreased as the delay between the onset of the noun and the green dot increased. There, however, appears to be no difference between the two verb constructions (causative vs. perception). I analyzed the data using

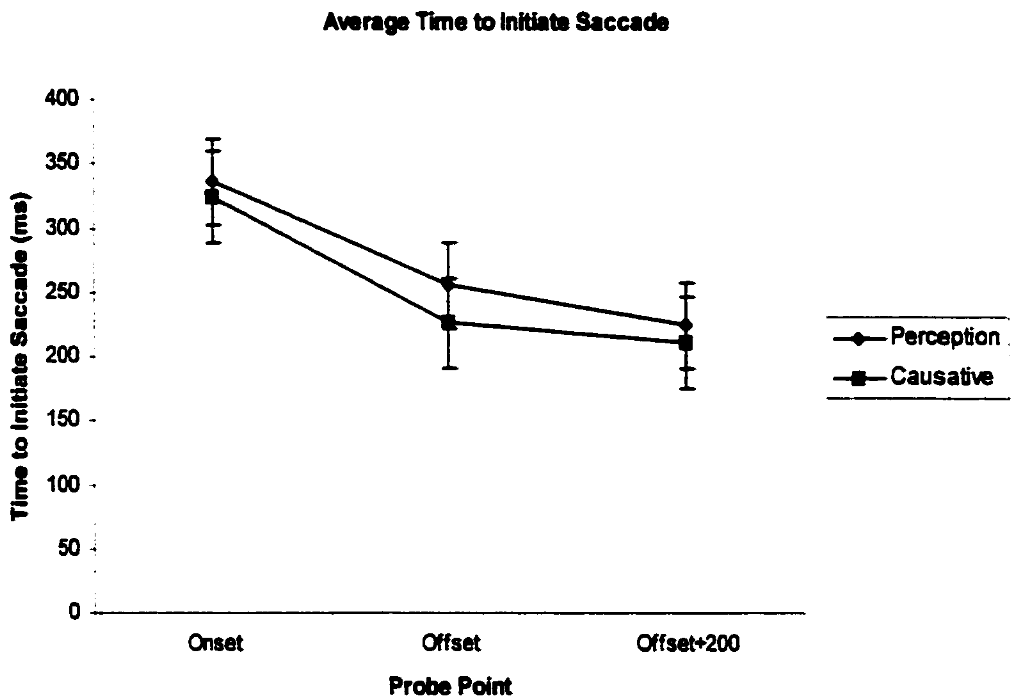


Figure 31. Average saccade onset to an object, for each probe point, averaged across subjects, in a memory matching task.

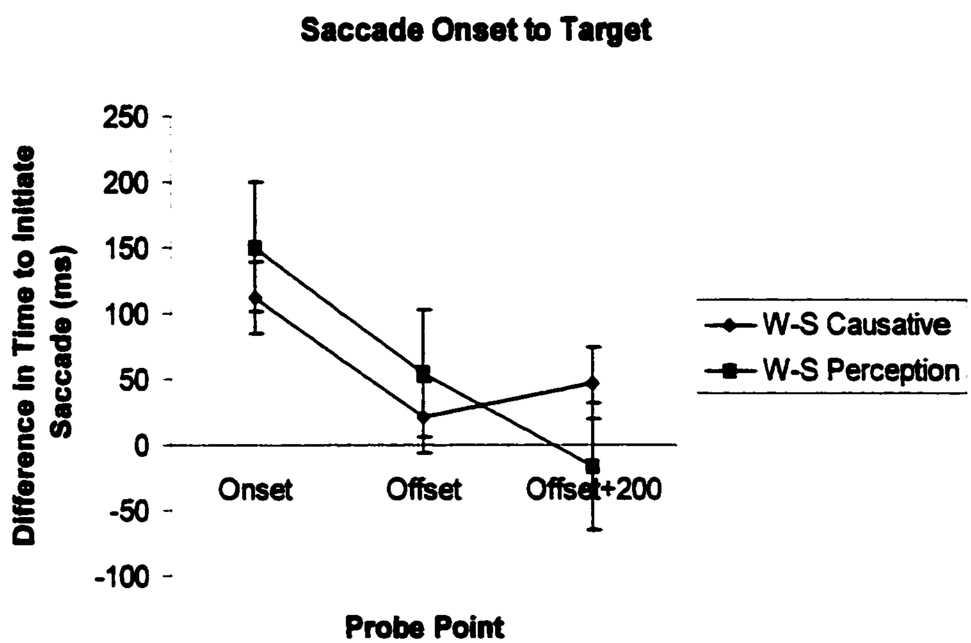


Figure 32. Average saccade onset to the target difference between presentation types, at each probe point, averaged across subjects, in a memory matching task.

a two-way repeated measures ANOVA (see Appendix D, Table 24). There was no statistically significant difference between probe points, $F(2,21) = 1.946$, $p = .1555$, and verb types, $F(1,21) = 0.075$, $p = .7875$.

In summary, as in Experiment 2 and 3, there was quite a large decrease in saccade onset time between the onset and offset probe points and then it leveled off, for average saccade onset time, and correct first saccade analyses. This suggests that the processing and programming of the target object was completed some time before the offset of the word. As well, subjects waited longer to initiate a saccade (regardless of whether it was to the correct object) for the earlier probe points, and for the perception verb types, indicating that they were waiting for the sentence to unfold, especially in the conditions with the perception verb where no information is provided that could help them predict the target object. Moreover, when observing the first saccade, the number of saccades to the incorrect object was not influenced by the type of competitor on the screen. Contrary to expectation, we did not find a statistically significant difference between verb types, suggesting that the constraining causative verbs did not appear to have facilitated performance. The same was found for pure verb effects where there was no statistically significant difference between the two verb constructions. Furthermore, subjects appear to have made quicker eye movements to the target object when it was presented within a sentence than when in isolation. This suggests that subjects either used some sentence context in aiding them to make predictions of the target object, or used a different strategy for each task.

Experiment 5

In this experiment, we used the information from Experiment 3 to track the time course of access to verb-complement information in a visual search task. We used the same stimuli and procedures as in Experiment 4 with the exception that we changed the memory matching task to a visual search task. We attempted to observe whether all saccade onset times obtained in Experiment 4 were due to memory effects.

Method

Subjects. 18 Concordia Psychology undergraduate students participated in this experiment. They participated either for course credit or for $5.00. All were native speakers of English and had normal or corrected-to-normal vision (20/20 Snellen).

Apparatus and Stimuli. The apparatus and stimuli used in this experiment were the same as in Experiment 4.

Procedure. The procedure was the same as in Experiment 4 with the exception of the matching task being replaced by a visual search task. To accomplish this we removed the initial presentation of the six pictures of objects when subjects were allowed to scan them freely. After completion of the consent form (see Appendix B6), subjects were presented the instructions on the screen (see Appendix C11). I then answered any questions they may have had. After the practice trials, as a reminder of the task at hand, subjects received a shorter version of the instructions (see Appendix C12). Each trial started with an asterisk. To begin each trials subjects pressed the yellow key on the button box. The asterisk was replaced with a red dot which subjects were asked to fixate.

After a delay of 20 ms, a sentence was uttered through the headphones. At one of three possible probe points (onset, offset, offset+200 ms of the noun) the pictures of objects appeared on the screen, and the dot turned green. Subjects' task was to find the picture of the target object (noun) just heard as quickly as possible. If the object was present, subjects fixated the object and pressed the green key. If they thought it was not present, they pressed the red key on the button box. The PC computer recorded saccade onset times and pixel coordinates of saccades and fixations.

Results and Discussion

Saccade onsets shorter than or greater than two standard deviations (SD) from the mean were replaced with the value of two SD above or below. Trials whereby subjects were not at fixation at the onset of the green dot were excluded. This excluded 6.94% of the trials. Results are shown in Figure 33 for words (nouns) presented in a sentence at each probe point for each verb type condition. Each point represents the time to initiate a saccade to the target object, averaged across all subjects. Inspection of Figure 33 shows that there was quite a large decrease in saccade onset times between the onset and offset probe point conditions and then it leveled off, regardless of the type of verb. There, however, appears to be no difference between the two classes of verbs in terms of average saccade onset time to the target object. As shown in Figure 34 we examined the time to initiate a saccade to the target object per item. Inspection of Figure 34 shows that there was a slight decrease in time to initiate a saccade to the target object from the onset to offset probe points, and then it levels off. There also appears to be a slight difference

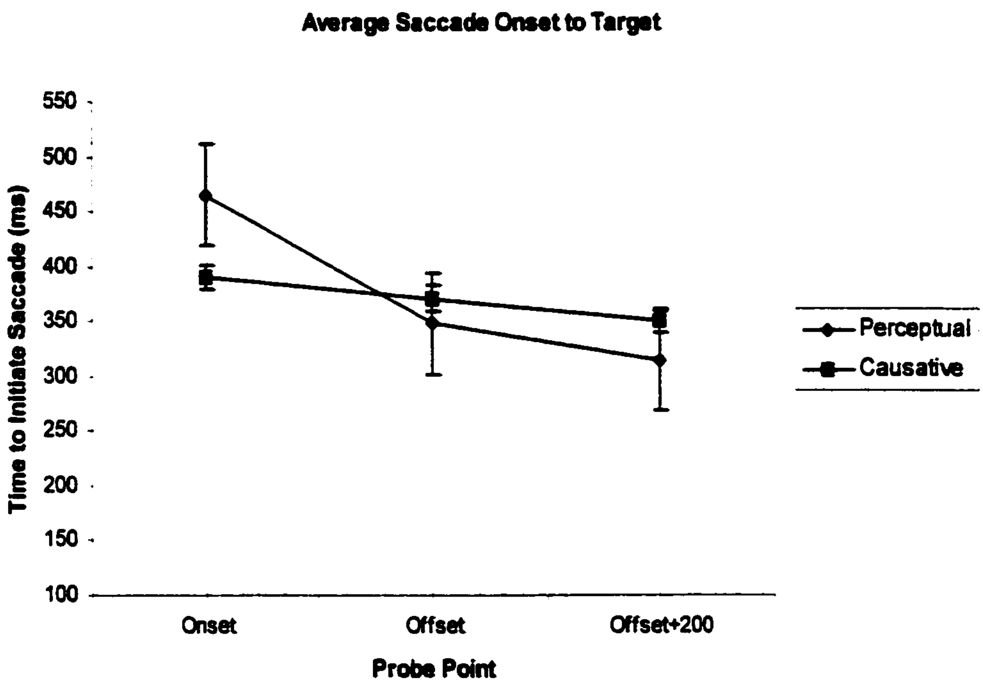


Figure 33. Average saccade onset to the target object within a sentence for each verb type, at each probe point, averaged across subjects, in a visual search task.

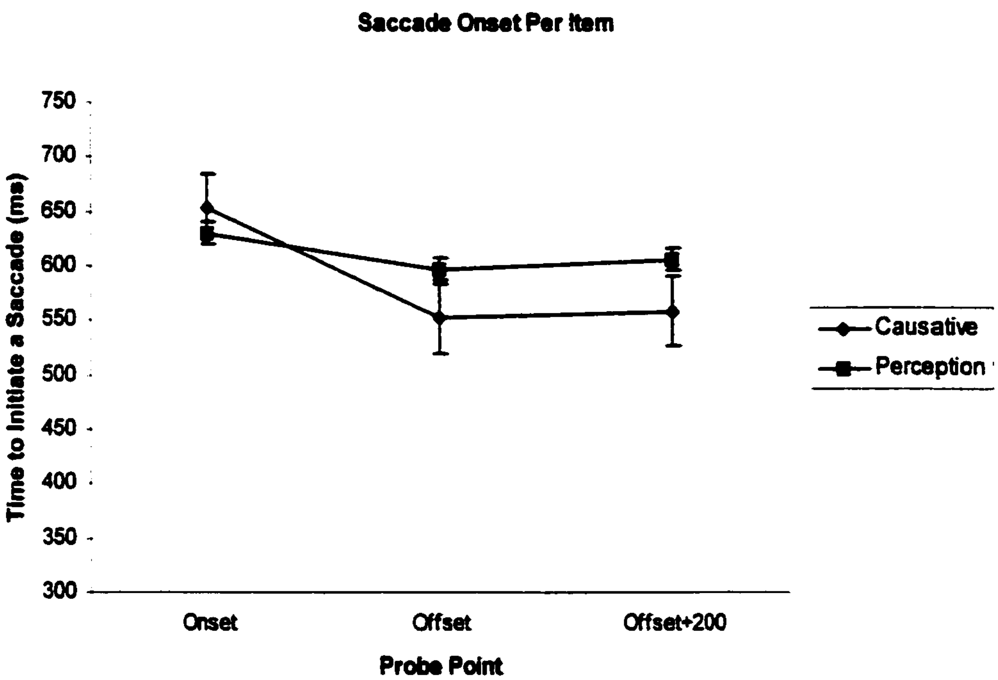


Figure 34. Average saccade onset per item, for each verb type, at each probe point, averaged across subjects, in a visual search task.

between the two classes of verbs for the offset and offset+200ms probe point conditions. We analyzed the data using two two-way repeated measures ANOVA (see Appendix D, Table 25 & 26). There was no statistically significant effect of probe point, $F1(2,12) = 0.388$, $p = .6823$, $F2(2,22) = 1.39$, $p = .2610$, and verb type, $F1(1,12) = 0.177$, $p = .6810$, $F(1,22) = 0.392$, $p = .5379$.

An analysis of time to initiate a saccade to the target object for words presented in a sentence at the first correct saccade could not be performed because of insufficient data points. Results are shown in Figure 35 for percentage of correct responses to the target object at the first saccade. Each point represents the percent correct responses to the target object at the first saccade, averaged across all subjects. Inspection of Figure 35 shows that there does not appear to be any trend across probe point conditions. There also appears to be a slight saccade onset time advantage for the causative verbs compared to the perceptual verbs for the onset and offset+200 ms probe point conditions. We analyzed the data using a two-way repeated measures ANOVA (see Appendix D, Table 27). There was no statistically significant effect of probe point, $F(2,17) = 1.23$, $p = .3042$, and verb type, $F(1,17) = 0.076$, $p = .7863$

Due to the large amount of errors at the first saccade (76.39 %) we inspected the percentage of errors in the first saccade for each type of competitor, as shown in Figure 36 for causative verbs and Figure 37 for perception verbs. Each point represents the percentage of responses to each competitor at the first saccade, averaged across subjects. The data were analyzed using two two-way repeated measures ANOVA (see Appendix

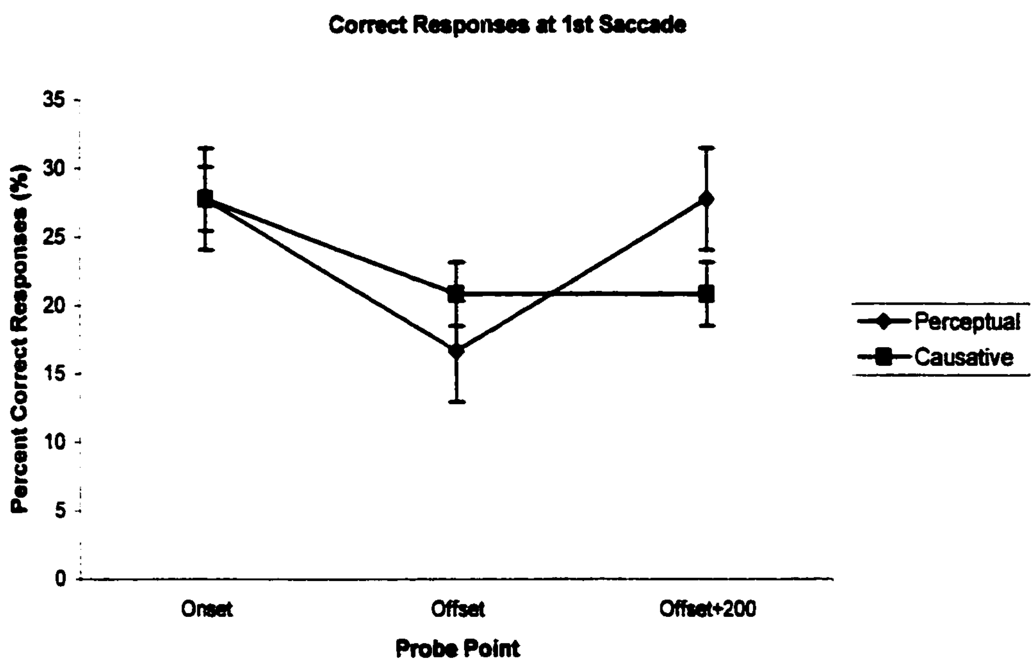


Figure 35. Percent correct responses at first saccade within a sentence for each verb type, at each delay, averaged across subjects, in a visual search task.

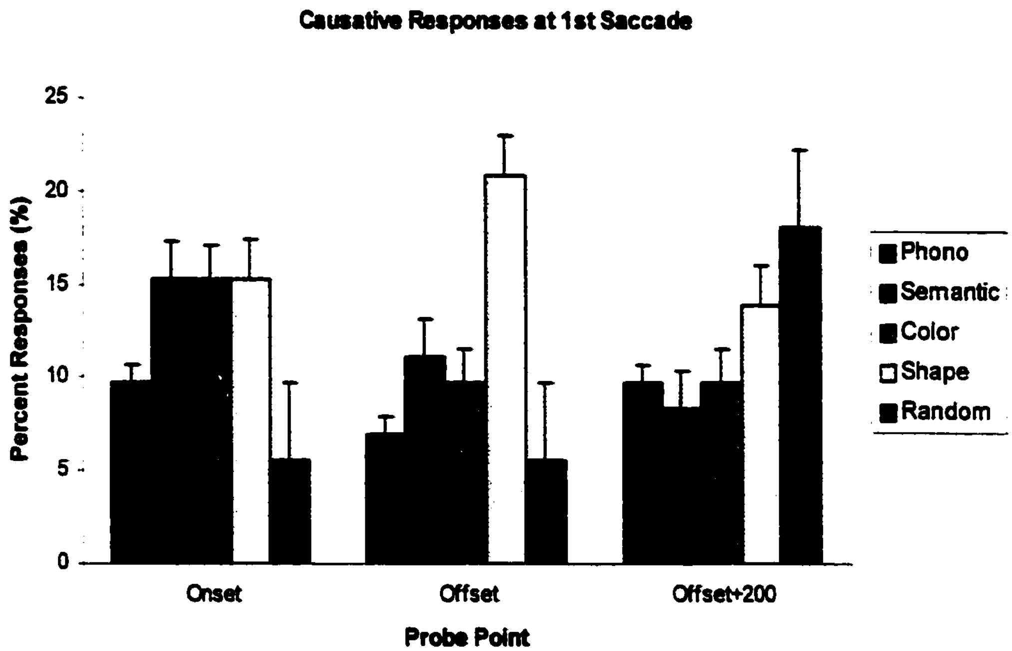


Figure 36. Percent responses to each competitor type, within a sentence for causative verb type, at each delay, averaged across subjects, in a visual search task.

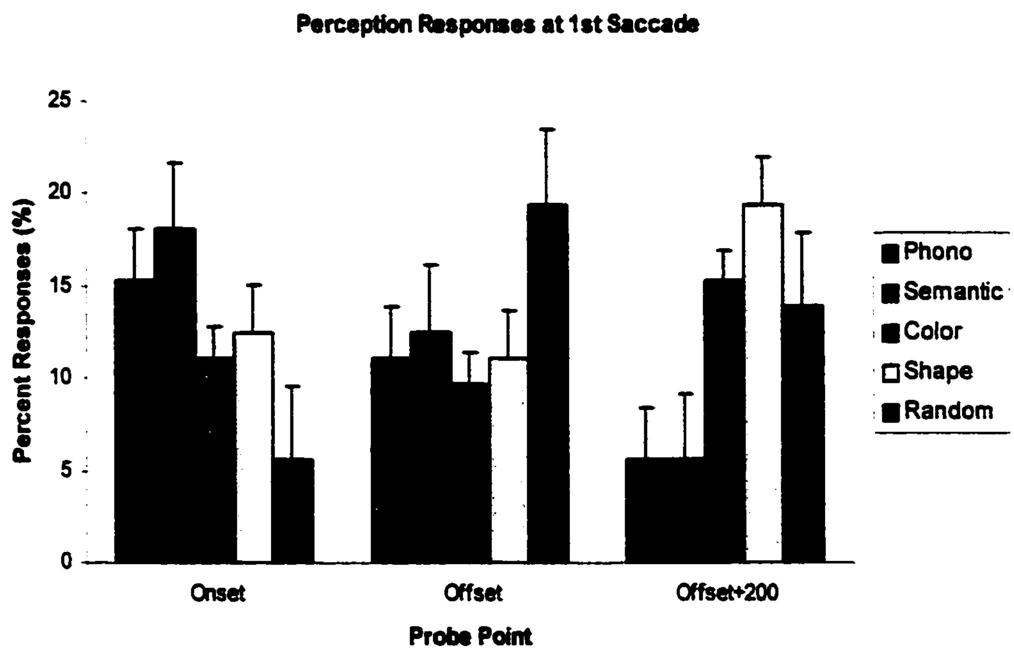


Figure 37. Percent responses to each competitor type, within a sentence for perception verb type, at each delay, averaged across subjects, in a visual search task.

D, Table 28 and 29). There was also no statistically significant difference between competitors, for the causative verb type $\underline{F}(4,17) = 1.78$, $\underline{p} = .142$ and for the perception verb type, $\underline{F}(4,17) = 0.335$, $\underline{p} = .854$. There was, however, a statistically significant interaction between type of competitor and probe point conditions, $\underline{F}(8,17) = 2.36$, $\underline{p} = .0209$. The results suggest that the semantic and phonological competitors had a greater effect on performance for the earlier probe points, while shape and color competitors had a greater effect on incorrect eye movements in later probe point conditions.

Furthermore, as shown in Figure 38, I examined the time to initiate the first saccade to an object, regardless of whether it was the target object. Each point represents the time to initiate the first saccade, averaged across subjects. Inspection of Figure 38 shows that there was a decrease in waiting time to initiate a saccade between the onset and offset probe point conditions, and then leveled off. There appears to be no difference between verb types. I analyzed the data using a two-way repeated measures ANOVA (see Appendix D, Table 30). There was a statistically significant difference between probe points, $\underline{F}(2,52) = 19.89$, $\underline{p} = <.0001$, but no statistically significant difference between verb types, $\underline{F}(1,52) = 0.164$, $\underline{p} = .6867$. We then conducted Tukey post-hoc pairwise comparisons (see Appendix D, Table 30), and they demonstrated that this difference lays between the onset and offset probe points, and onset and offset+200 ms probe point conditions.

Moreover, as shown in Figure 39, I obtained the pure verb effect values by taking the measurements of saccade onsets to the target noun when presented in isolation and subtracted from it the saccade onsets to the target noun in the sentence experiment.

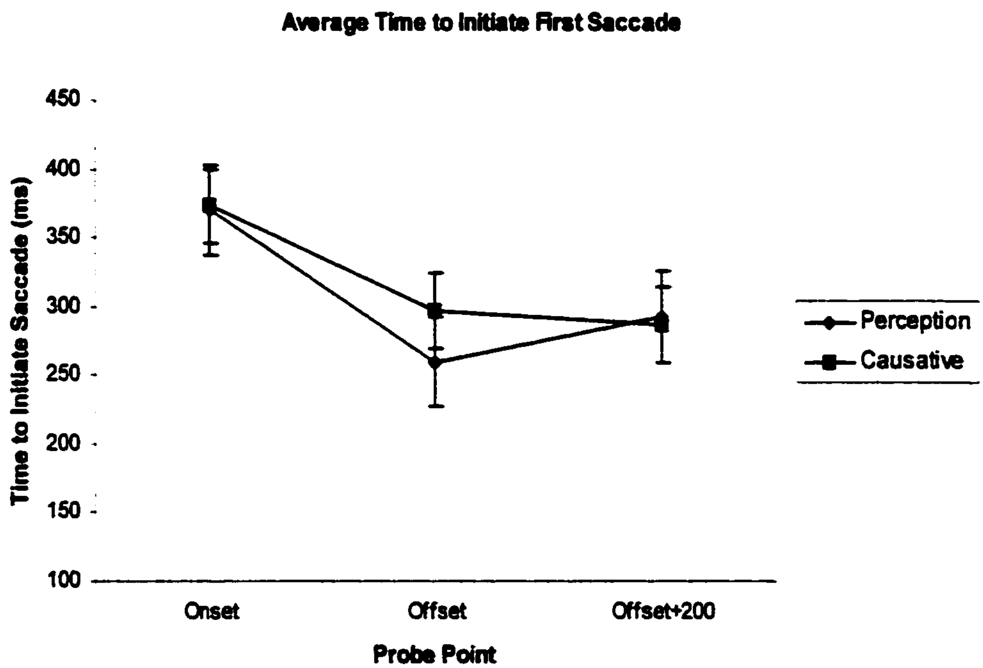


Figure 38. Average saccade to an object, for each verb type, at each probe point, averaged across subjects, in a visual search task.

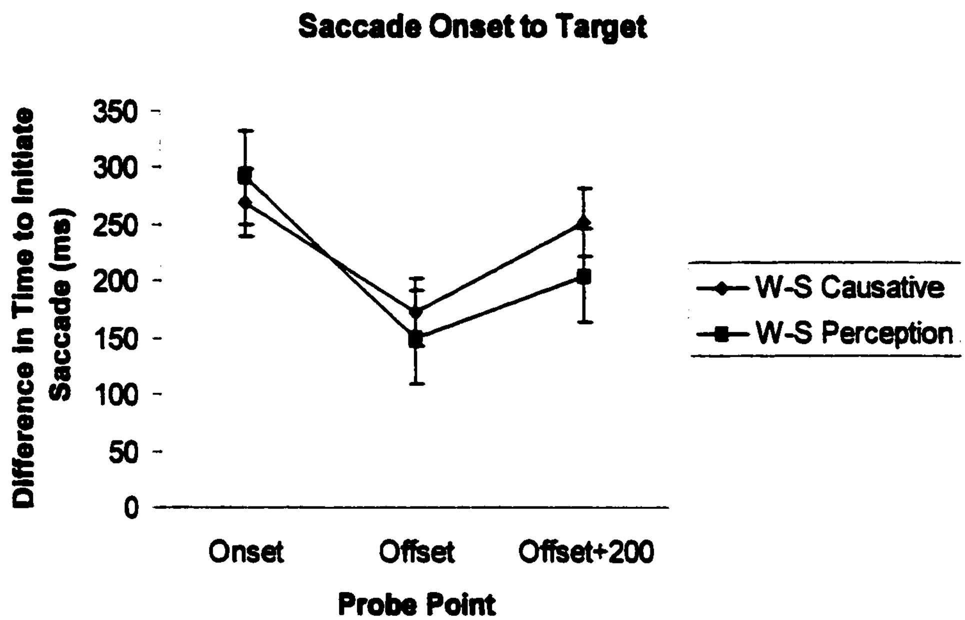


Figure 39. Average saccade onset to the target difference between presentation types, at each probe point, averaged across subjects, in a visual search task.

Each point represents the difference between the average time to initiate a saccade to the target object for each type of presentation (in isolation vs. in a sentence), averaged across subjects. Inspection of Figure 39 shows that the values are all positive indicating that subjects performed more quickly when the noun was presented within a sentence than in isolation, and there appears to be no difference between the two verb constructions (causative vs. perception). I analyzed the data using a two-way repeated measures ANOVA (see Appendix D, Table 31). There was no statistically significant difference of probe point $F(2,22) = 2.019$, $p = 0.1449$., and verb type $F(1,22) = 0.076$, $p = 0.7851$.

As a final analysis, I compared subjects' performance on each task. Results for average time to initiate a saccade results are shown in Figure 40 comparing words presented using a memory matching task and a visual search task. Each point in Figure 40 represents the average time to initiate a saccade to the target object, at each probe point, across tasks and averaged across subjects. Inspection of Figure 40 shows that subjects had faster average saccade onset times to the target object in the visual search task. I analyzed the results using a two-way repeated measures ANOVA (see Appendix D, Table 32). There was a statistically significant difference between the two tasks for the average saccade onset, $F(1,31) = 26.67$, $p = <.0001$.

As shown in Figure 41, I also examined the percentage of correct responses to the target object at the first saccade. Each point represents the percent correct responses to the target object at the first saccade, across tasks, averaged across all subjects. Inspection of Figure 41 shows that there appears to be no trend across tasks. I analyzed the data using two one-way repeated measures ANOVA (see Appendix D, Table 33). There

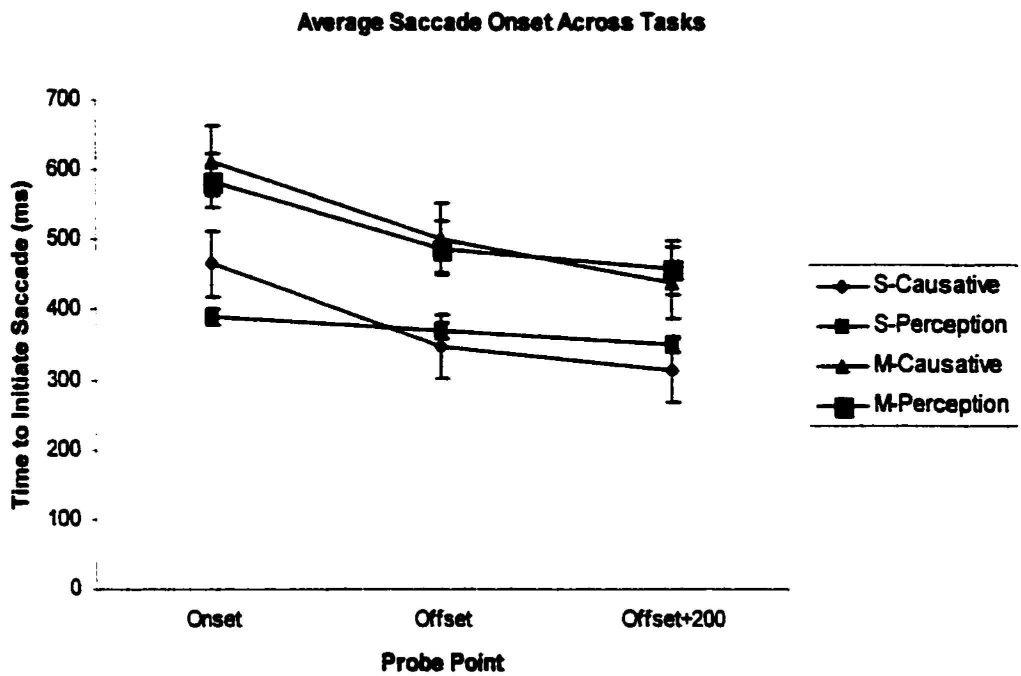


Figure 40. Average saccade onset to target object at each probe point, across tasks, averaged across subjects, when presented within a sentence.

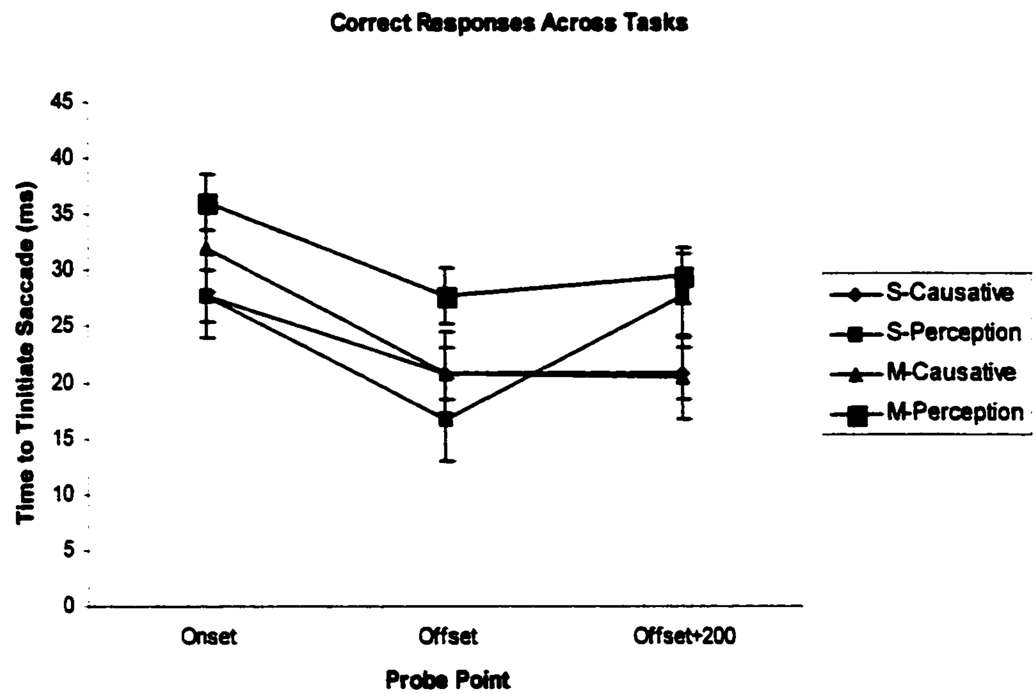


Figure 41. Percent correct responses at first saccade, at each probe point, across tasks, averaged across subjects, when presented within a sentence.

was no statistically significant difference between the two tasks, $F(1,35) = 1.75$, $p = .1942$.

In summary, there was no difference across probe points and verb type in average saccade onset times, correct responses, and per item analyses during a visual search task. Furthermore, contrary to expectation, we did not find a statistically significant difference between verb types, suggesting that the constraining causative verbs did not appear to have facilitated performance. The same was found for pure verb effects where there was no statistically significant difference between the two verb constructions. Furthermore, subjects appear to have made quicker eye movements to the target object when it was presented within a sentence than when in isolation. This suggests that subjects either used some sentence context in aiding them to make predictions of the target object, or used a different strategy for each task.

Moreover, subjects waited significantly longer to initiate the first saccade at earlier probe points, indicating that they were waiting for the word to unfold until the recognition point was reached. For the number of incorrect saccades there did not appear to be any difference between competitor types. There was, however, a significant interaction, whereby the semantic and phonological were stronger competitors for the onset probe point conditions, while shape and color were stronger competitors in the offset+200ms probe point conditions.

Finally, when comparing performance on the two tasks, subjects were quicker to initiate a saccade to the target object in the visual search task, but performed equally well on both tasks. This suggests that subjects are using different strategies for both tasks, and that that used in the memory matching task actually hinders performance.

General Discussion

In this series of experiments, I attempted to study the role of visual representation in the access to argument and conceptual structures of verbs during sentence processing. I used an eye-tracking paradigm in which subjects heard sentences while looking at pictures of objects displayed on a computer screen. Overall, I found a statistically significant difference between probe points, in both types of constructions of sentences (causative vs. perception), suggesting that subjects initiated a saccade to the target object before its offset. However, I did not find a statistically significant difference between the sentences that contained a verb conceptually related to its direct object (causative), and the sentences that contained a neutral transitive verb (perception) during the presentation of the target noun and 200 ms after its offset. The same results were found for pure verb effects, which were obtained by subtracting the average time to initiate a saccade to the target object when presented in isolation from the amount of time to initiate a saccade to the target object when presented in a sentence. These results thus failed to support the view that semantic information extracted from highly constraining causative verb is able to guide visual attention towards the appropriate object in a visual display even before the semantic properties of the direct object becomes available.

This pattern was found regardless of the task used, whether subjects examined the set of objects before hearing the accompanying sentence (memory matching task) or as the sentence was being uttered (visual search task). In fact, there was a statistically significant difference in performance between the two tasks. Prior viewing of the display allowed for overall quicker eye movements to the target object when presented in isolation, but slower eye movements to the target object when presented in a sentence.

These results imply that subjects were using different strategies for each task, and that this was advantageous in one condition but not in the other. Furthermore, subjects waited longer to initiate the first saccade (regardless of whether it was to the target object) in the perception conditions, and made quicker eye movements to the target object when it was presented within a sentence, than when presented in isolation. These results, on the other hand, could possibly suggest that either context effects were influencing performance, or subjects were again using different strategies for each task and attempting to predict (yet incorrectly) the target object when it was presented in a sentence, especially in the causative conditions. It is interesting to note, however, that subjects first saccades were often incorrect (approximately 75% of the time), implying that subjects either: a) failed to remember the position of the target object, or b) were making "incorrect" associations (e.g. "spill-water", rather than "spill-milk") and thus searching for the wrong object, or c) were searching for two objects in parallel, the target object and its semantically associated object which were both plausible referents, or d) were more distracted by the competitor objects in the causative conditions because they were formulating a linguistic, perceptual or conceptual representation of the target object. Further research, as will be mentioned below, would be needed to clarify these results.

These results, therefore, do not appear to support Altmann and Kamide's claim that the language processor can activate representations due to the predictive nature of verb arguments, and that these arguments are evaluated according to the thematic fit between the entities in the current context in which the unfolding is occurring and the verb. This incongruency in results may be explained by the stronger verb associations in the constraining conditions (e.g. "eat-cake"), than the less constraining conditions (e.g.

"move-cake") in Altmann and Kamide's study. These possible intra-lexical effects, as explained earlier, were controlled for in this study by collecting normative data. These negative findings are in accordance with the autonomous proponents who argue that context cannot be involved in generating alternatives prior to lexical output, but rather can only contribute to the evaluation and integration of this output. Thus, proponents such as Frazier would argue that listeners construct a single representation of a sentence based solely on grammatical principles. Like the autonomists, therefore, I do not argue against the claim that there exist a clear integration between visual and linguistic representations and that this interaction is crucial for language interpretation in real-world contexts. What I do, however, argue from the current eye movement results, is that during the early stages of language comprehension the system appears to rely primarily on structural analyses of linguistic representations, and that this is done independently of the conceptual interpretation of the input.

Although I believe this new methodology accounts for many factors which were not controlled for in previous studies (as mentioned earlier), there are some limitations that need to be addressed in future studies. First, although I controlled for preferred verb complements and pictures chosen to represent each noun, by collecting normative data, I did not do so for the choice of the set of competitors for each target noun. These sets of pictures were chosen by the experimenter to match the target object on the different dimensions (shape, color, semantics, and phonology). To ensure these choices follow consensus, however, these competitors would need to be normed. Moreover, the similarity between the competitor objects in these dimensions and the frequency rates of the objects chosen should be controlled. Furthermore, to strengthen the claim that there is to be no significant effect of verb-representation on eye movements, I believe that a control experiment should be added, whereby within the set of pictures there are no competitor objects that are designed to distract the subject from the target object.

Second, for certain instances of the sentence constructions, the optimal verb-noun complement was not chosen because that noun object could not be easily portrayed as a picture. For example, with the sentence "break-ice", "ice" is not easily represented visually. In this case I took the second most popular response, which was "break-vase". Thus, other possible verb-noun complements should be chosen to replace those instances where the optimal complement object cannot be easily represented visually. In fact, not being able to examine the time course of language comprehension using abstract words and concepts (e.g. "love" and "law") is an unfortunate limitation for any study whereby listeners are presented with visual displays.

Third, the scanning time provided to the subjects to examine the set of six objects (6000 ms) may not have been sufficient for subjects to adequately scan and process each object and its location. This may explain why subjects at the first saccade looked at the incorrect object approximately 75% of the time. Thus, the same experiments should be conducted with longer scanning times in order to ensure that a failure to find any effect is not due to our choice of delay. A counterargument can be made, however, that in every day life, scenes of dozens of objects are flashed in front of us for very brief periods of time, and we do not go about actively scanning each object. Care must be taken, therefore, in not giving subjects too long a scanning time, which may lead the design to lose its already minimal ecological validity.

In fact, in some studies it has been found that subjects are not required to scan objects in a display in order to find the target object while conducting a visual search task. In a study by Grindley & Townsend (1970), subjects were asked to say where, among a set of complex patterns, the test object was situated (about which they were informed of either visually or verbally). The whole display was presented at a brief exposure time in order to prevent scanning by the eyes. In both experiments it was found that knowing beforehand what the test object was gave a significantly higher accuracy rate than knowledge given simultaneously or after the presentation of the display. This could explain why subjects made a saccade to the target object more quickly in the memory-matching task than in the visual search task. Moreover, it can be argued that these results may provide evidence that there is some extra processing occurring that is not made available by simply looking at eye movements. More specifically, subjects may be using their attentional spotlight to search the display, without making any eye movements, and this paradigm does not allow measurement of this. This appears to be quite unlikely, however, since it has been found in many studies, that eye movements are done incrementally as the word or sentence unfolds (Eberhard et al., 1995; Tanenhaus et al., 1995; Sedivy et al., 1999)

Furthermore, comparing the current memory-matching data and visual search data may not be the most effective method to examine the effects of previous viewing on eye-movement performance. The visual search task should be compared to a memory-matching task whereby the tasks differ along only one factor, knowledge of the set of objects before the advent of the sentence. Currently, in the memory-matching task, subjects have an advantage over the subjects in the visual search task because they are made aware not only of the set of objects in each display, but also the location of each object. By changing the position of the objects at the second presentation, the two tasks would only differ in terms of the knowledge about the set of display objects, thus providing a more accurate comparison of the two tasks.

Finally, some would argue that the reason why no effect of verb-specific representations on eye-movements was found might be from the choice of probe points. More, specifically, because subjects were asked not to move their eyes during the presentation of the verb, it may have prevented the possibility of seeing the effects triggered by the verb. I argue that by preventing subjects from performing eye movements during the presentation of the verb should not have inhibited them from programming the proper saccade to the target object. Thus, I believe that while the dot is red subjects are programming their first saccade. Thus, if the constraining verb were to aid in determining the target object, sometime within its presentation, then rapid eye movements to the correct objects should be initiated at the onset of the green dot in the onset probe point condition. In order to support this claim, however, this alternative should also be tested empirically, by adding probe points within the presentation time of the verb.

This new eye-tracking methodology could be used to test a multitude of effects. We are currently in the process of designing a study looking at whether visual representations can aid in disambiguating sentences with prepositional phrases (PP). This will be achieved by adding a PP at the end of the same sentences as were used in this present study. For instance, "The boy dropped the ball in the net". This sentence is ambiguous because "in the net" can either refer to the location of where the ball was dropped (i.e. The boy dropped the ball into the net), or as a modifier of ball (i.e. The boy dropped the ball that was in the net). Thus, using these sentences, we could examine the time-course of subject's eye movements as the sentence unfolds to determine which construction is most likely, even when the visual context biases subjects towards the opposite construction (e.g. A ball and a net shown separately, versus a ball shown inside the net).

A second study we will undertake is to examine the effects of discourse context on language comprehension, and on resolving ambiguous sentences. Before displaying the set of objects and the accompanying sentence, we would provide subjects with a few sentences that would give the listeners a context in which the event is occurring. For example, "After the soccer practice the boy was collecting the soccer balls which were spread out across the field. He thought that he had collected all of the balls, until he saw one last one situated in the net and walked towards it to pick it up. The boy dropped the ball in the net". This will either provide evidence that discourse context can have an effect on which interpretation is preferred or provide support to the argument that the language processor bases its decision simply on the principles of minimal attachment and late closure, with no early interference from context.

Finally, in another study, we would like to present the set of objects in a realistic visual scene. We would first begin with a still image, projected on a screen in front of the listeners, and eventually progress to short movies whereby subjects are presented in the midst of acting upon certain objects in the scene. For example, we could manipulate the convergence between the object represented in the scene versus that mentioned in the utterance; or the feasibility of the subject performing the action on the object portrayed in the scene, either due to distance of the target object from the subject, or the position of the subject (e.g. facing back to the object) in regards to the target object; or the amount of thematic fit between the verb and its complement direct object uttered in the sentence or displayed in the scene. To our knowledge movie displays have never been used, and would give us greater ecological validity in examining the effects of verb and visual representations in sentence comprehension.

In closing, research on the role of visual representations in the access to argument and conceptual structures of verbs during sentence processing, using the eye tracking paradigm is new and needs to be investigated further. Based on the results of the present study, these further investigations would benefit of this new methodology, which appears to be quite efficient and accurate. Furthermore, it allows experimenters to vary and control many factors, which was not possible using some previous methodologies.

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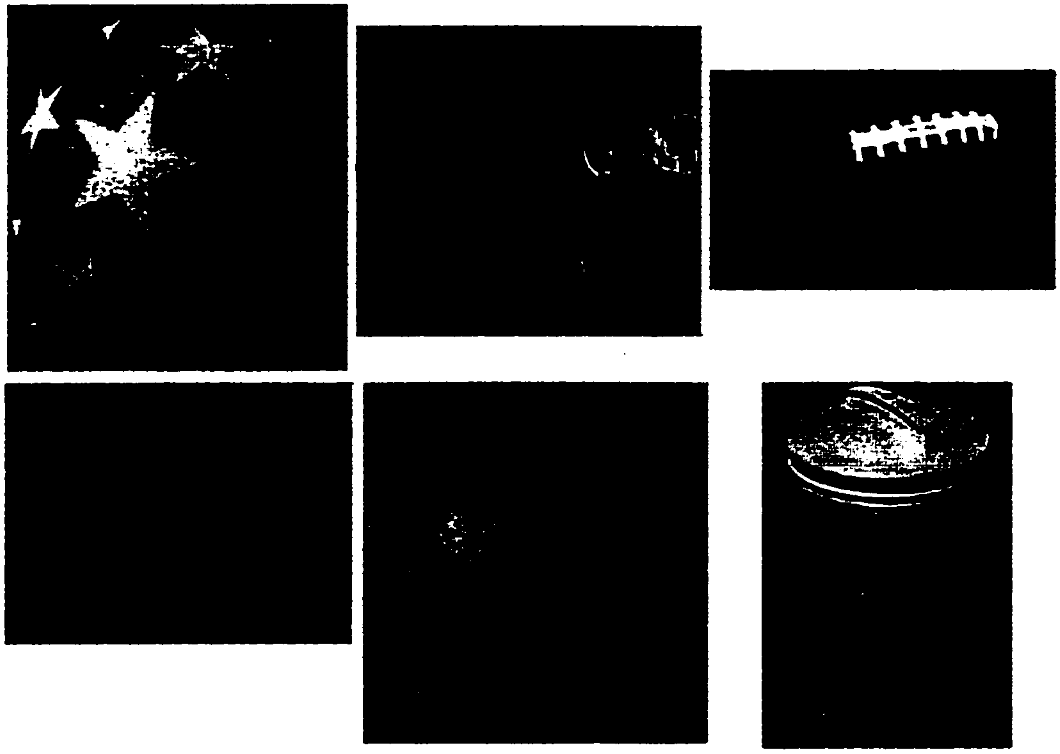
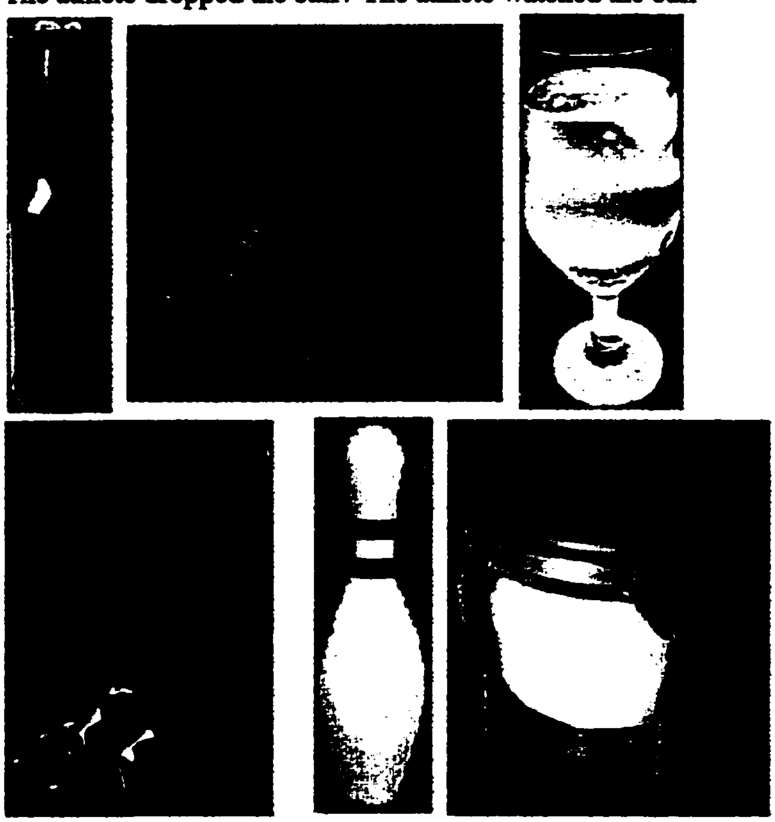
Appendix A

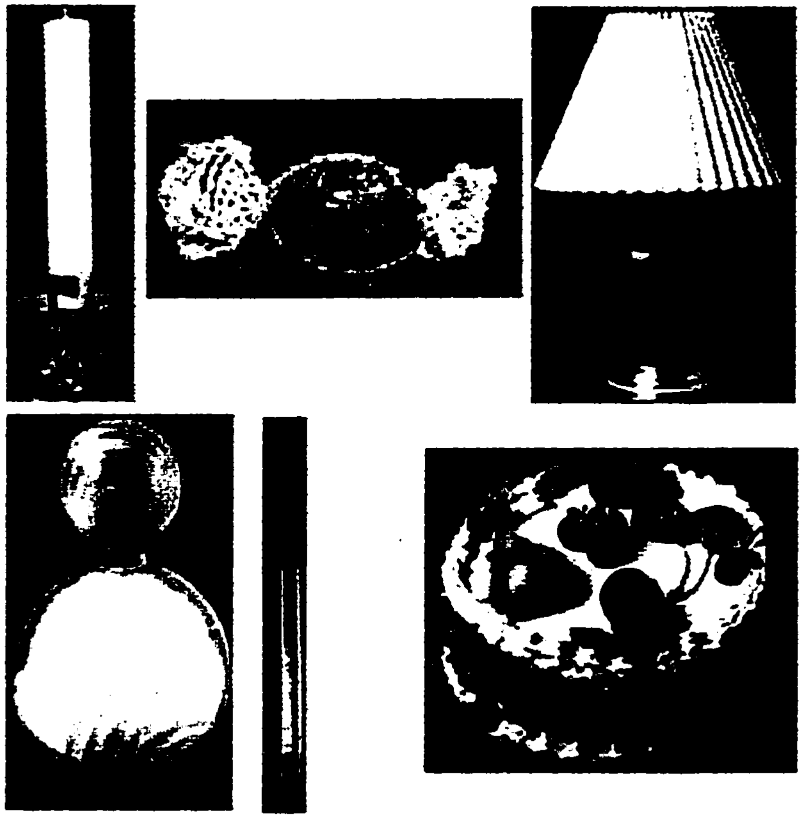
Stimuli Used for Experiments 1, 2, 3, 4, & 5



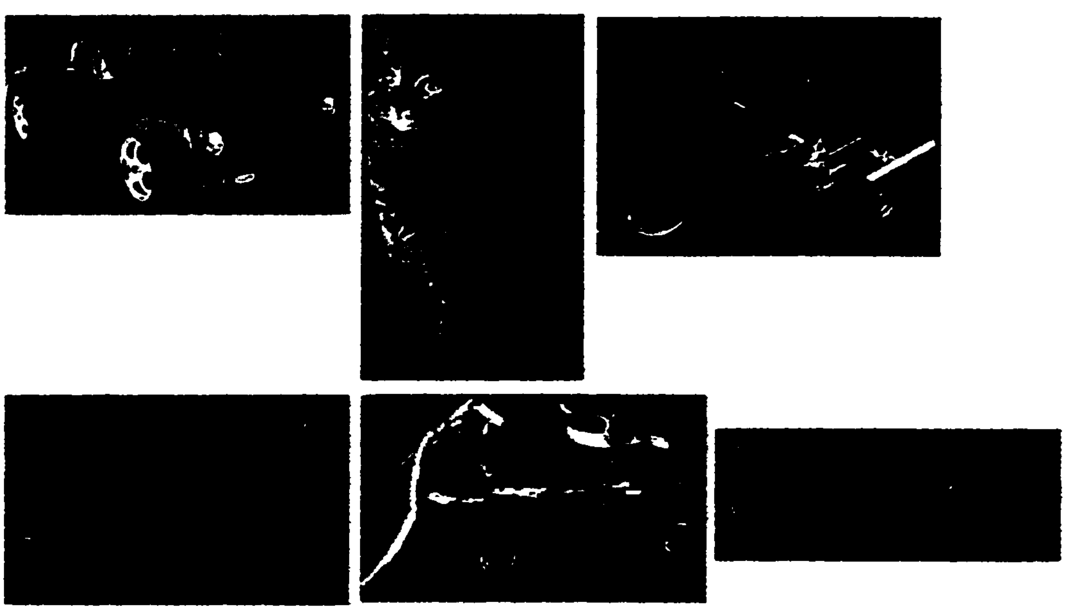
The athlete dropped the ball / The athlete watched the ball



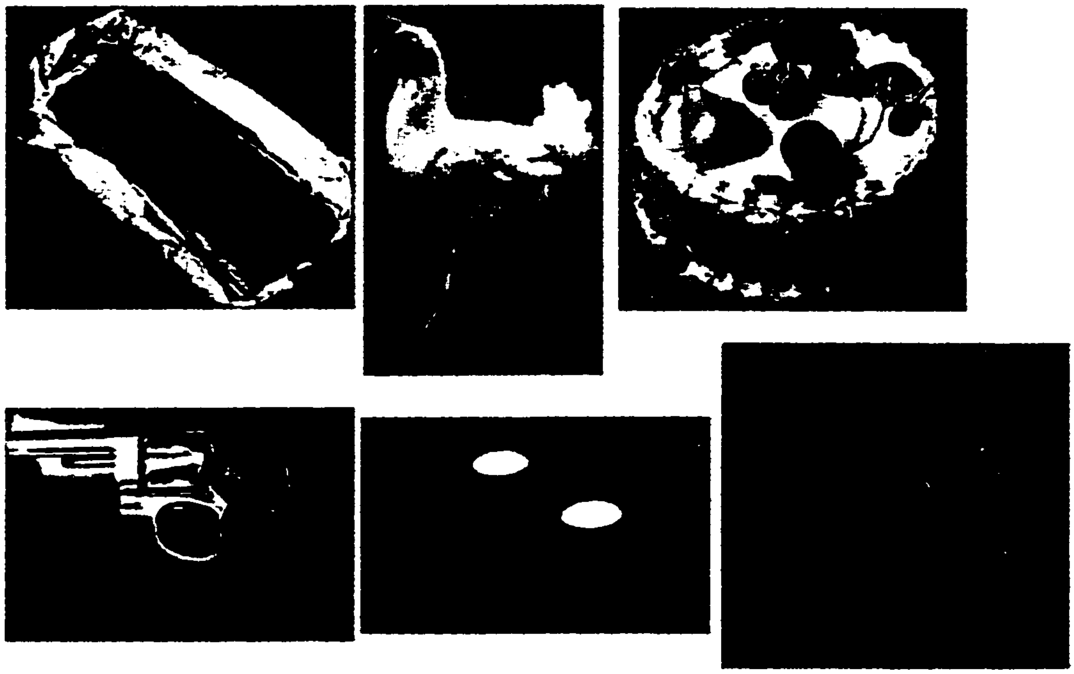
The teenager spun the bottle / The teenager scented the bottle



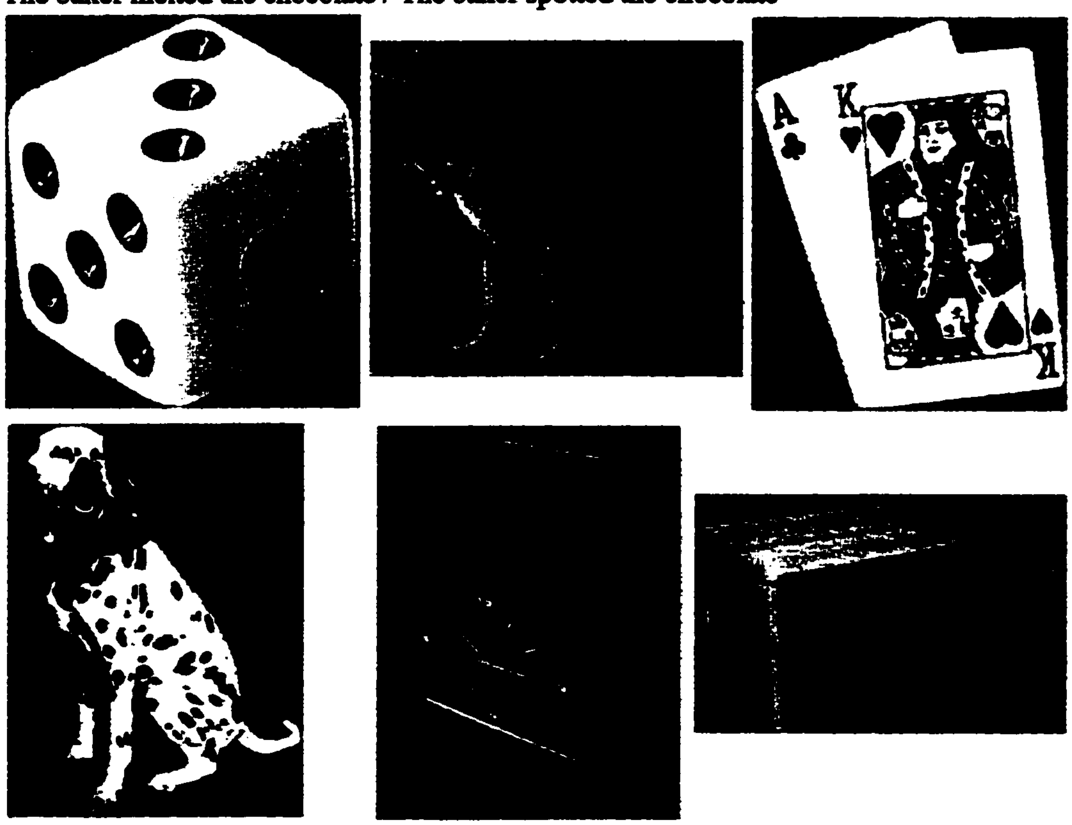
The waitress burned the candle / The waitress felt the candle



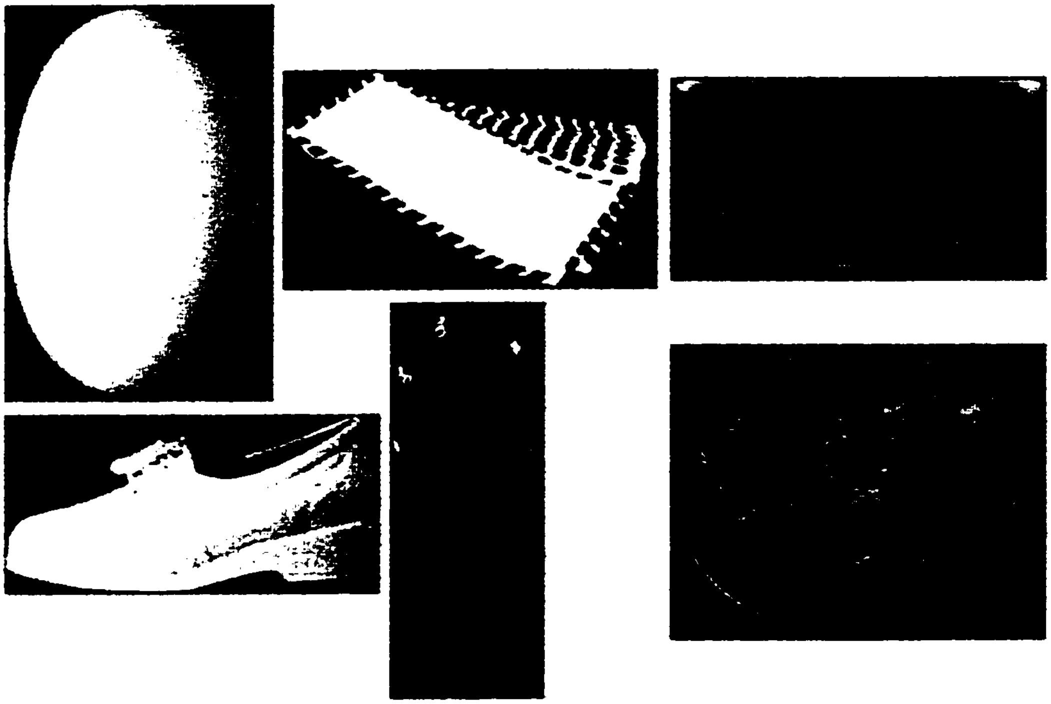
The driver started the car / The driver smelled the car



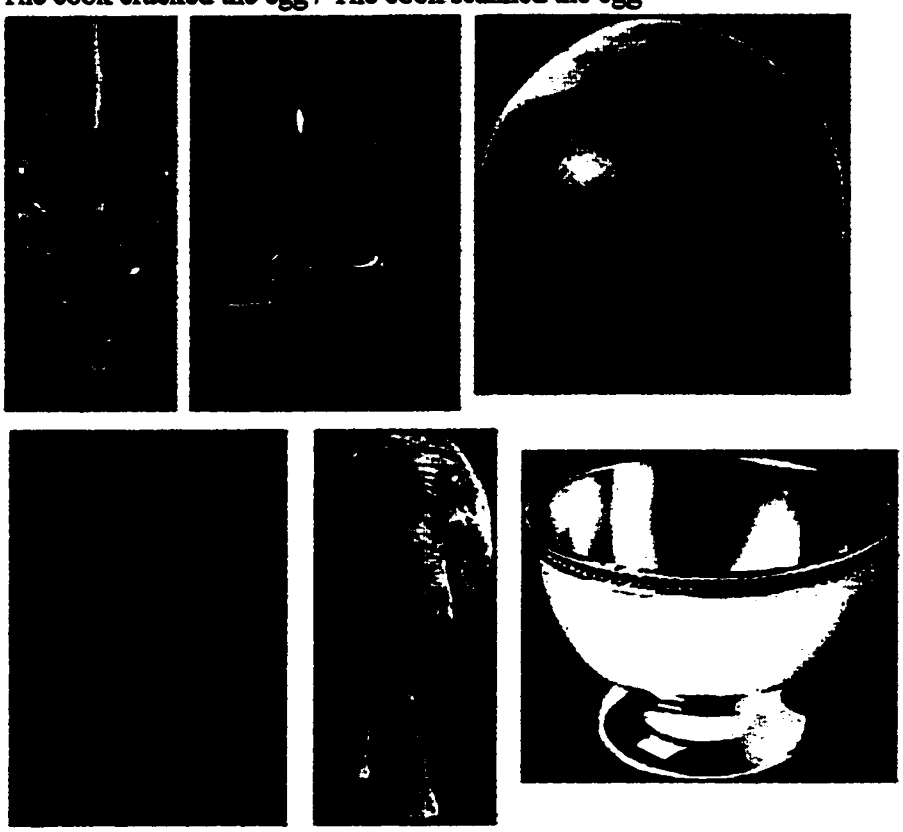
The baker melted the chocolate / The baker spotted the chocolate



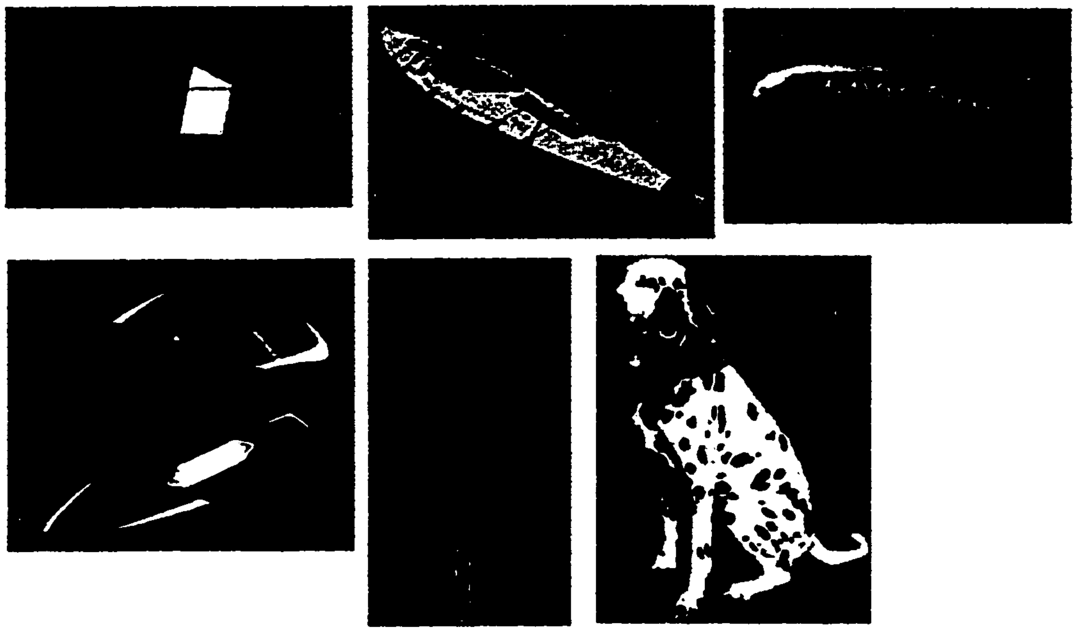
The gambler rolled the dice / The gambler noted the dice



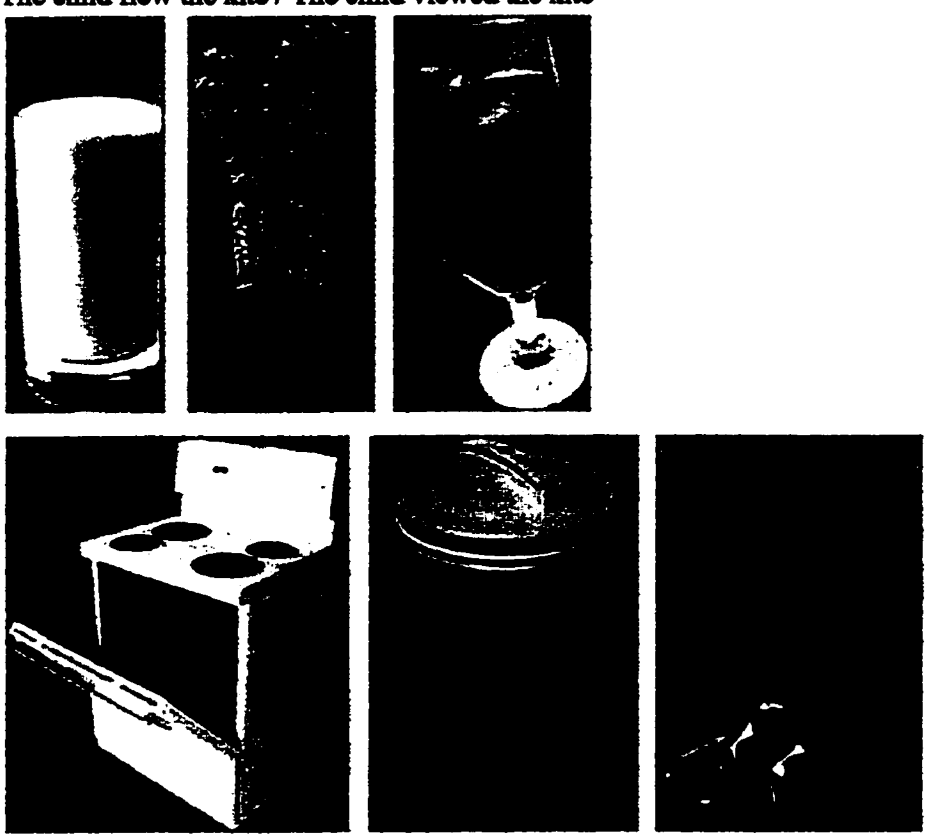
The cook cracked the egg / The cook scanned the egg



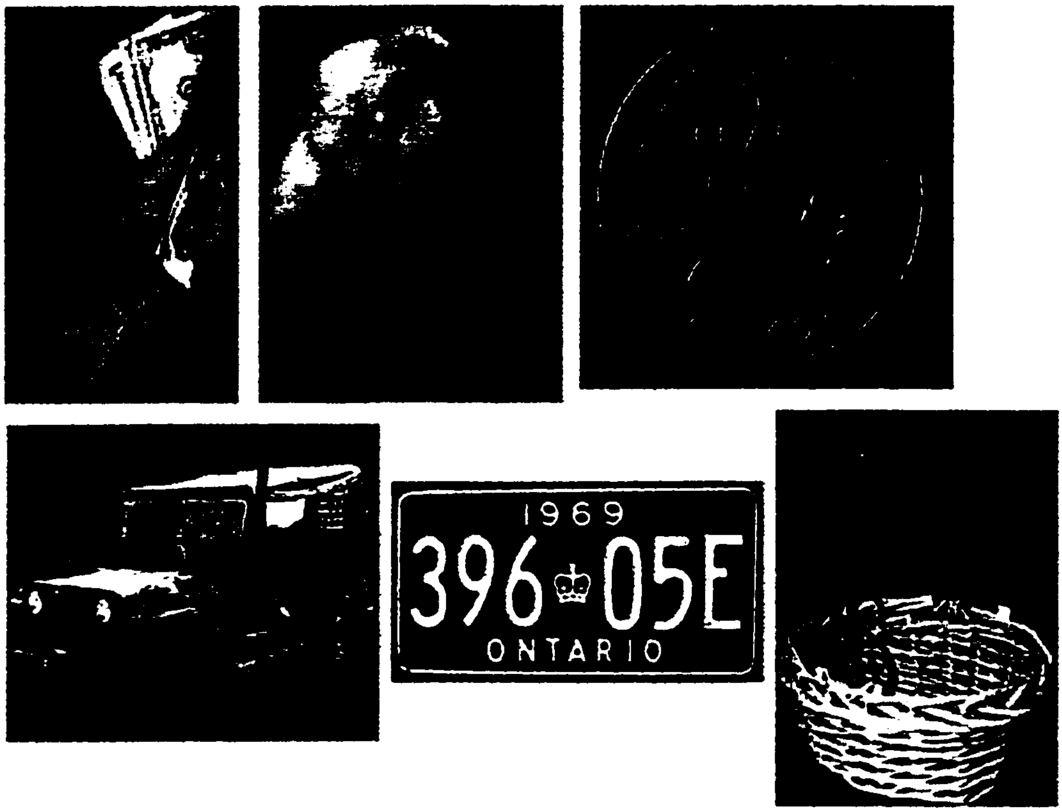
The farmer crushed the grapes / The farmer spied the grapes



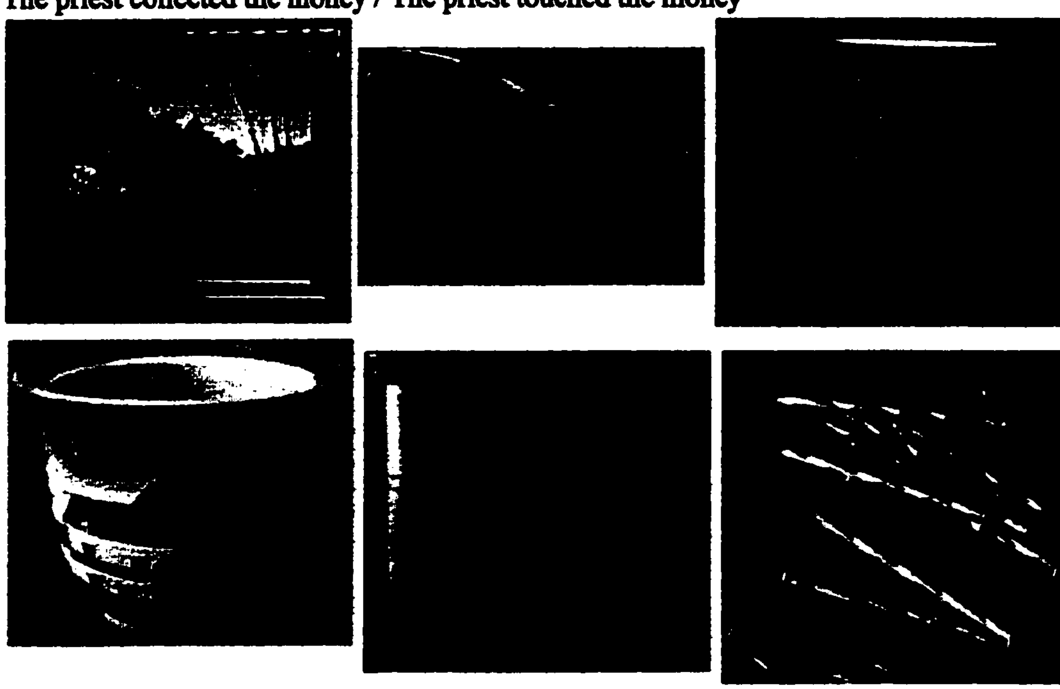
The child flew the kite / The child viewed the kite



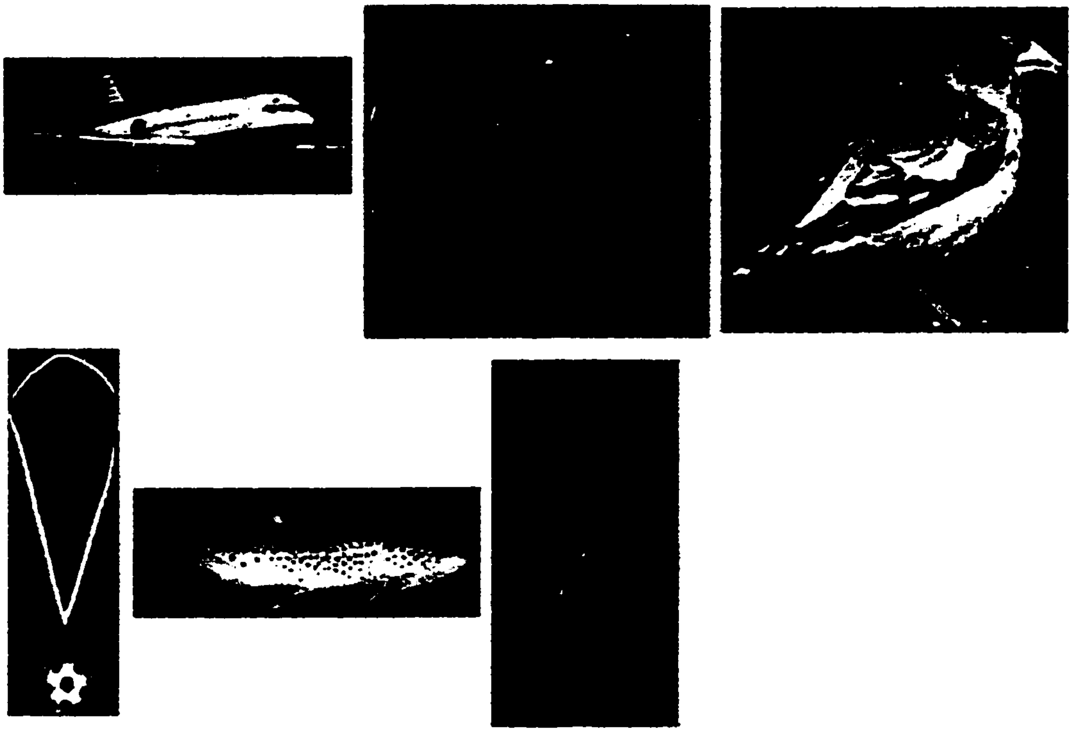
The baby spilled the milk / The baby sensed the milk



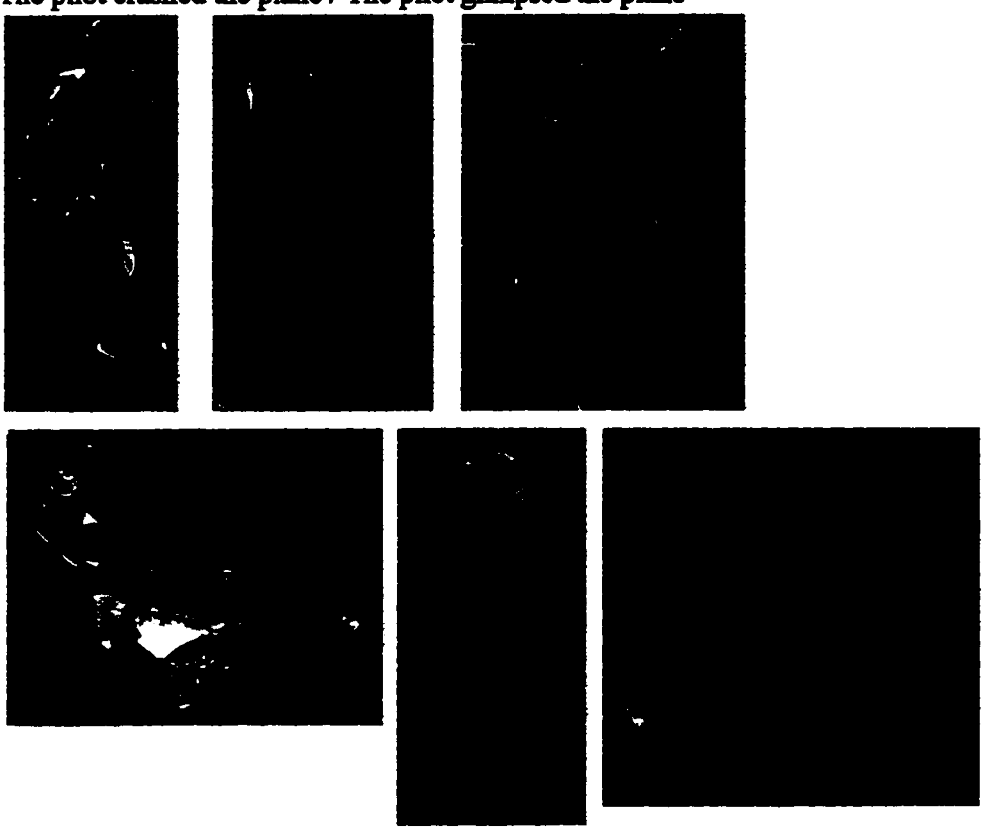
The priest collected the money / The priest touched the money



The painter hung the picture / The painter eyed the picture

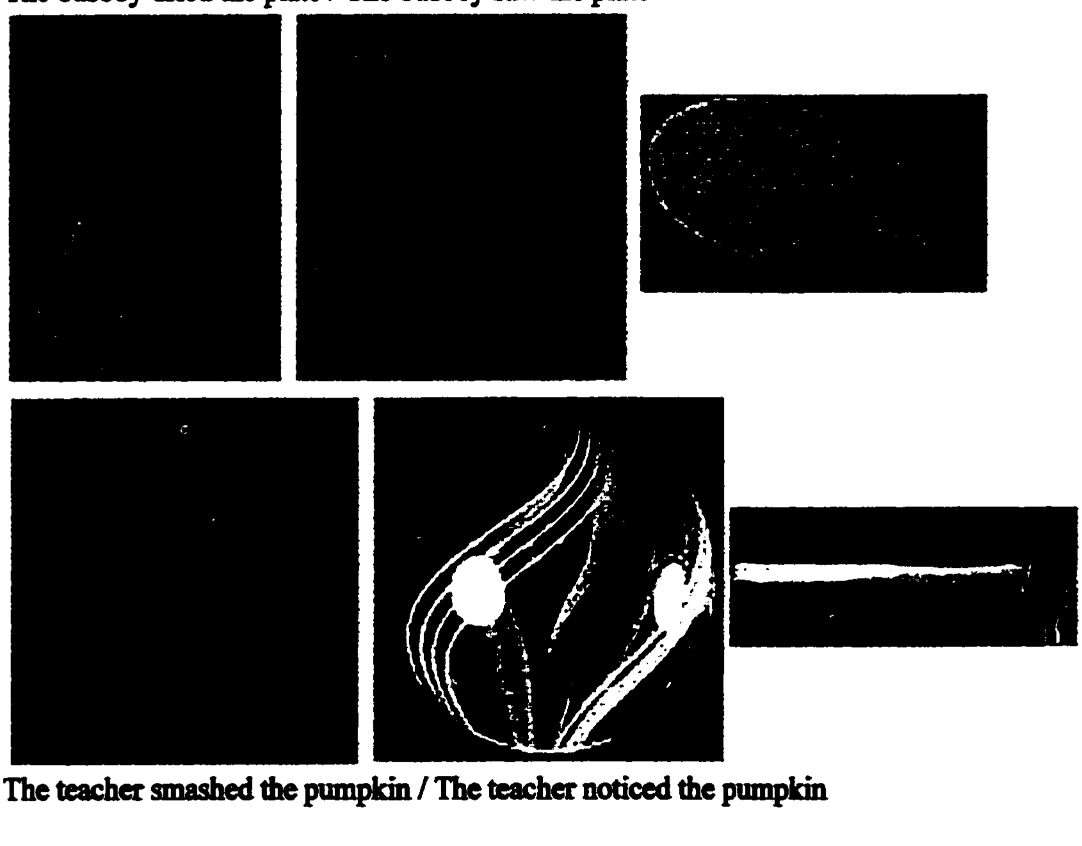


The pilot crashed the plane / The pilot glimpsed the plane

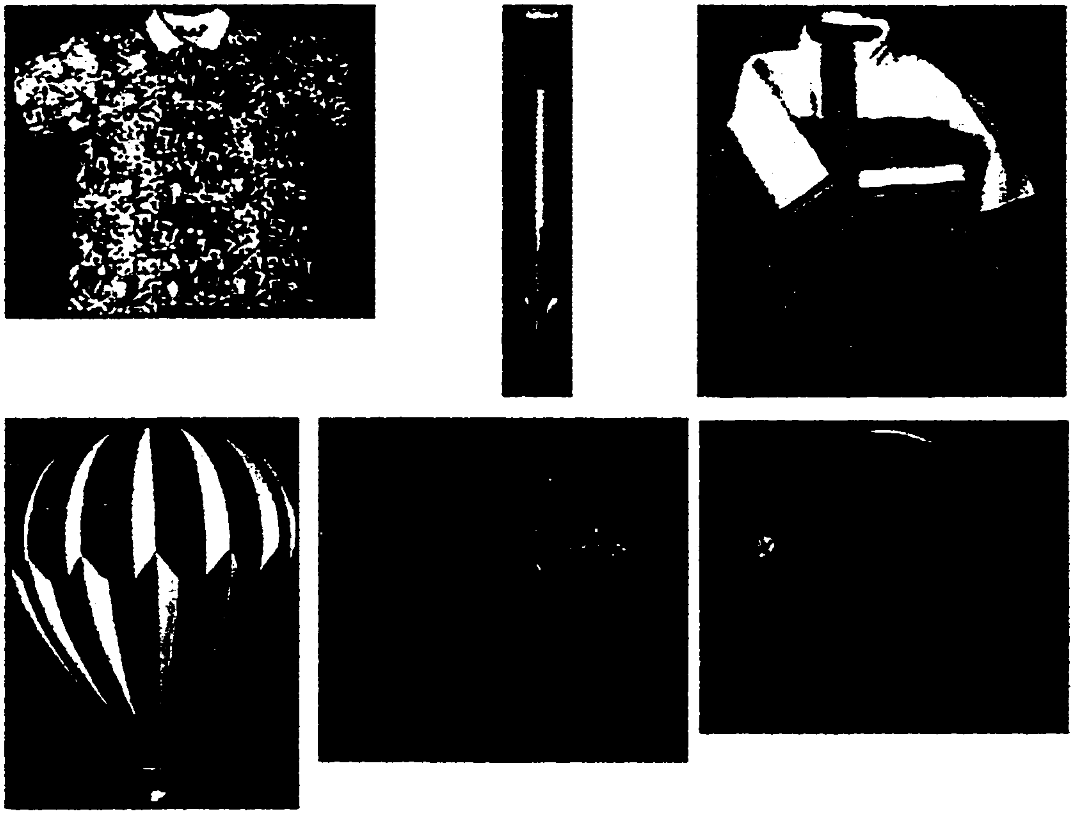


The gardener grew the plant / The gardener studied the plant

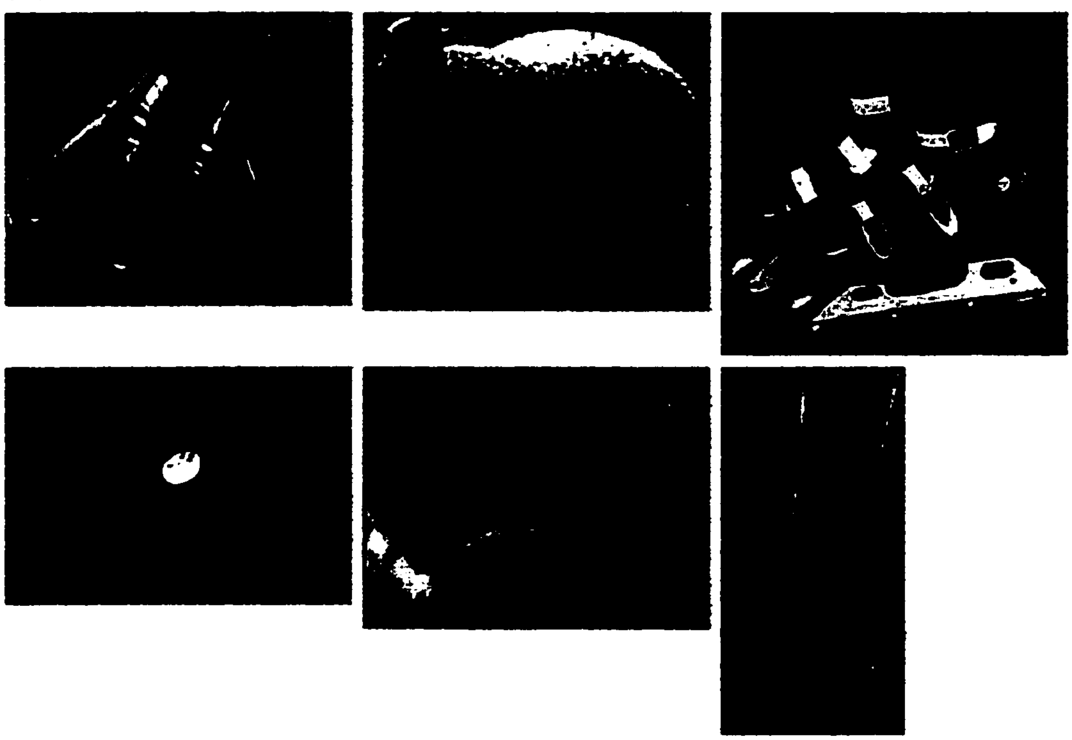
The busboy dried the plate / The busboy saw the plate



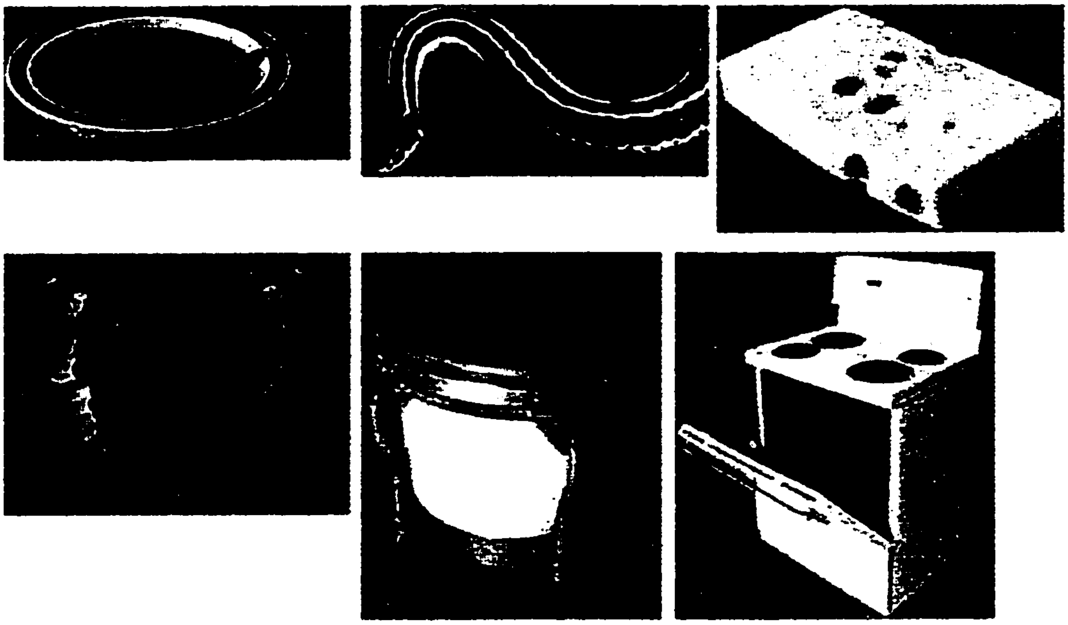
The teacher smashed the pumpkin / The teacher noticed the pumpkin



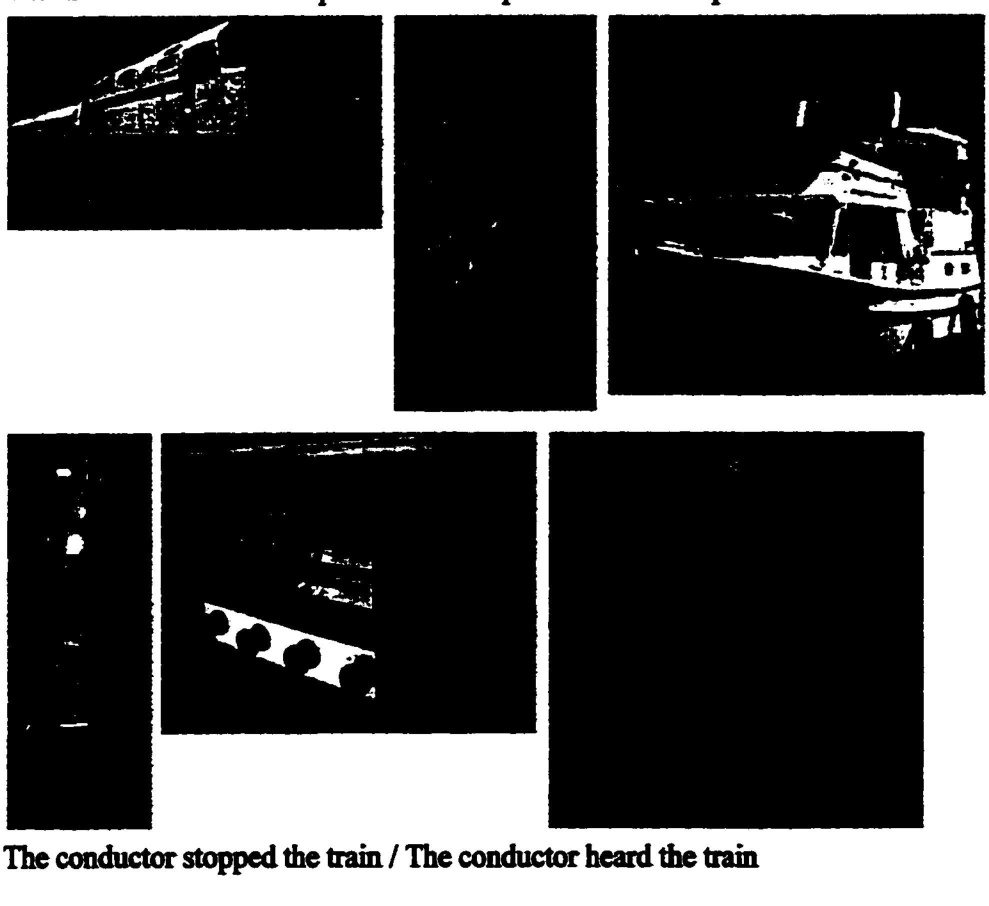
The traveler wrinkled the shirt / The traveler detected the shirt



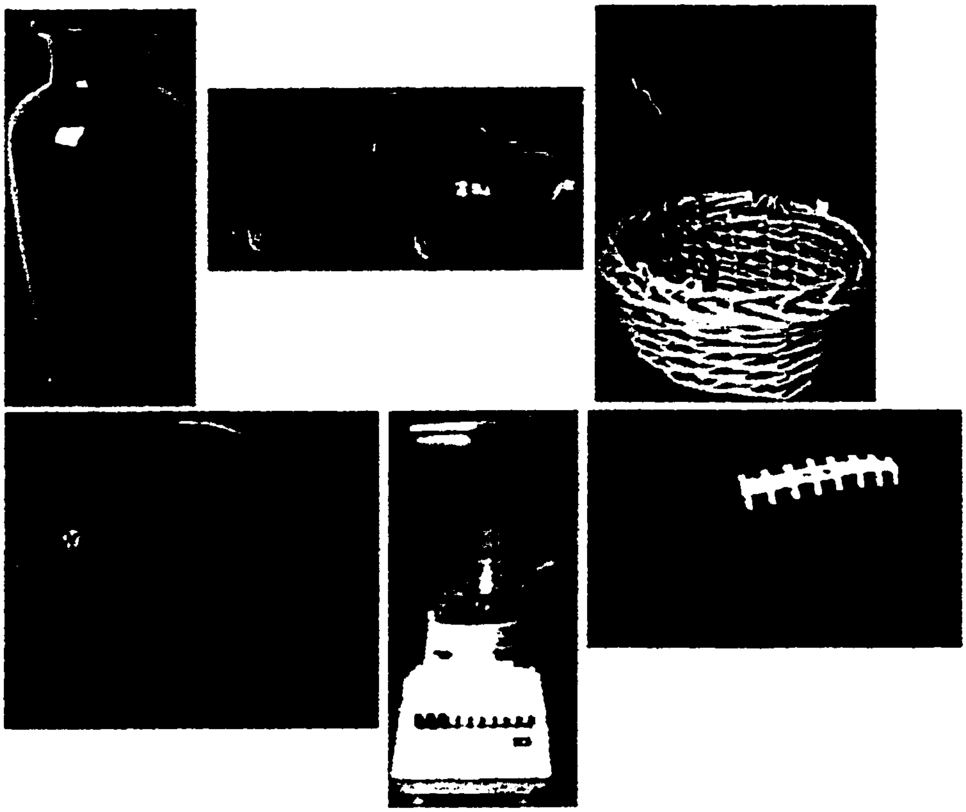
The father shined the shoes / The father observed the shoes



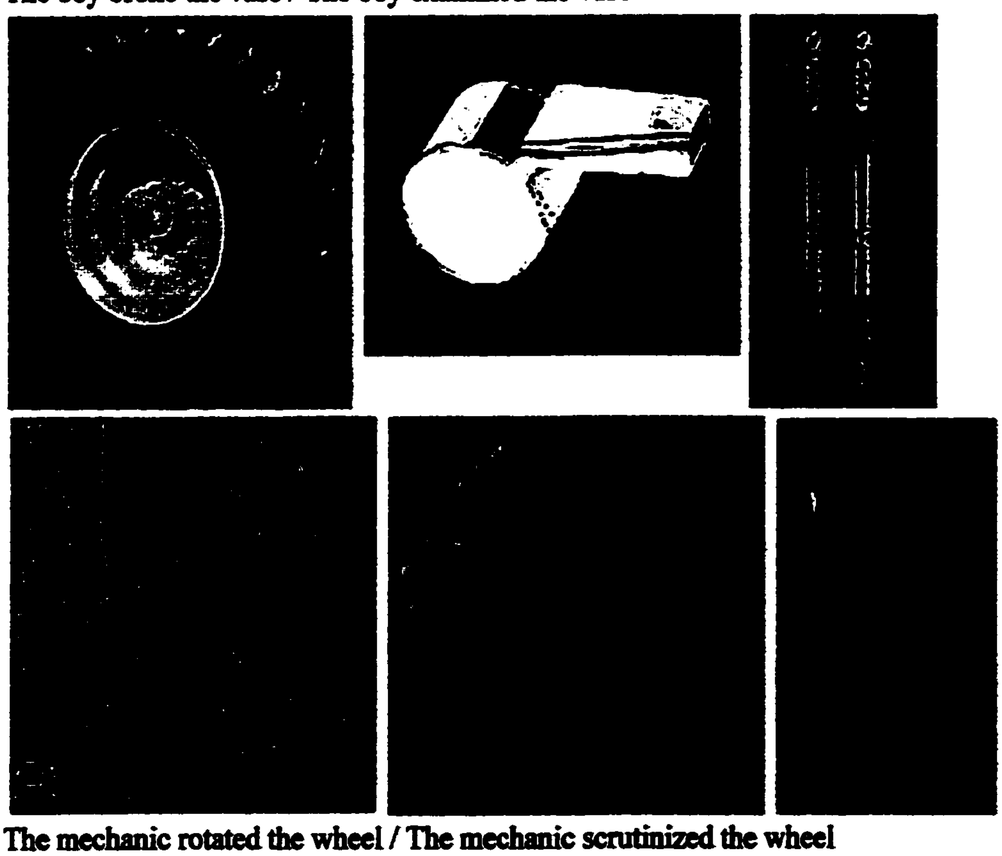
The mother heated the soup / The mother perceived the soup



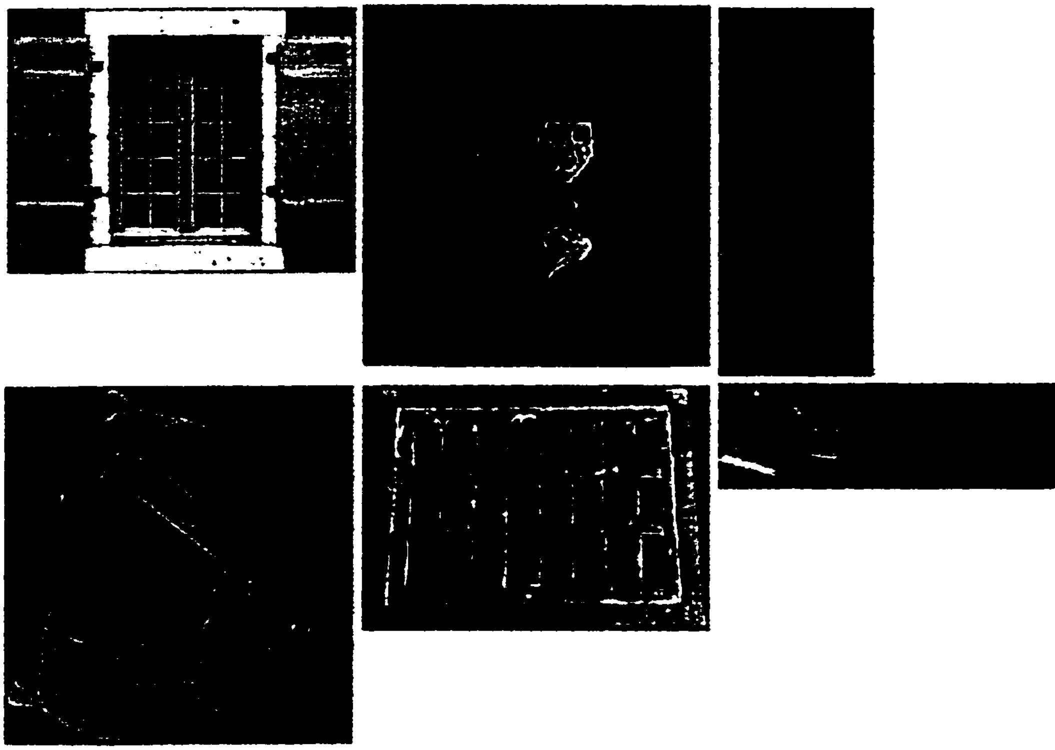
The conductor stopped the train / The conductor heard the train



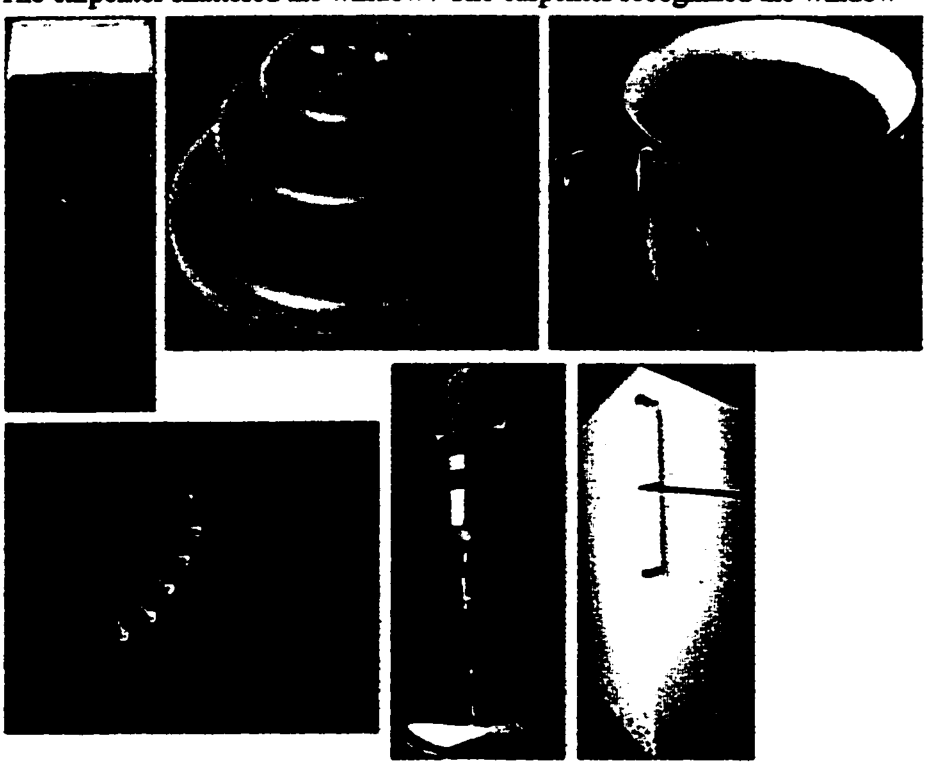
The boy broke the vase / The boy examined the vase



The mechanic rotated the wheel / The mechanic scrutinized the wheel



The carpenter shattered the window / The carpenter recognized the window



The waiter chilled the wine / The waiter witnessed the wine

Filler Sentences

The child drank the juice
The farmer ate the sandwich
The boy walked the dog
The pilot landed the plane
The player kicked the can
The teenager scratched the CD
The boy used the skateboard
The student read the book
The busboy washed the pan
The mechanic fixed the truck
The baker opened the jar
The butcher cut the meat
The worker pressed the button
The teacher corrected the exam
The cook tapped the dough
The man wrote the poem
The mother ironed the pants
The mailman closed the package
The athlete ran the race
The father removed the toy
The secretary typed the letter
The boxer punched the man
The jeweler rated the diamond
The woman bought the tickets
The grandmother rocked the chair
The farmer pulled the cart
The mother pushed the carriage
The teenager played the stereo
The student practiced the guitar
The woman baked the pie
The waiter moved the table
The artist made the present
The designer created the dress
The boy finished the puzzle
The girl skipped the rope
The man covered the telephone

Appendix B

Consent Forms for Experiments 1a, 1b, 2, 3, 4, & 5

Appendix B1

CONSENT FORM TO PARTICIPATE IN RESEARCH

This is to state that I agree to participate in a program of research being conducted by Caroline van de Velde of the Department of Psychology at Concordia University, in conjunction with her Master's Thesis project, under the supervision of Dr. Michael von Grunau.

A. PURPOSE

I have been informed that the purpose of the research is to investigate how the brain processes visual information and it's interaction with language. This is being conducted to partially fulfill the requirements for a Master's Thesis.

B. PROCEDURES

I have been informed that the experiment involves the following procedures: Pictures of objects will be shown successively in the center of the computer screen. An asterisk will be shown at the center of the screen before every picture, this will signal where the picture will be located. It is important to keep your eyes on this asterisk in order to not miss the pictures that will be flashed on the screen. My task will be to say as quickly as I can, into the microphone, the name of the objects on the screen. When the computer has recorded the response, a beep will be heard. I understand that if no beep is heard, this means that I did not say the name of the object quick enough, or clearly enough for the microphone to pick up my response. Thus, it is important to say your response as quickly and as clearly as possible.
The completion of the experiment will take about 5 minutes. I have been informed that my name will not be associated with my data in the experiment. I understand that my participation in the experiment, and the information and data I provide, will be kept strictly confidential. I understand that if the results are published, individual data will be reported but I will be only indicated as "Subject" and then a number.

C. CONDITIONS OF PARTICIPATION

- I understand that I am free to decline to participate in the experiment without negative consequences.
- I understand that I am free to withdraw my consent and discontinue my participation at anytime without negative consequences.
- I understand that my participation in this study is confidential (i.e., the researcher will know, but my identity will not be disclosed).
- I understand that my data from this research may be published.
- I understand the purpose of this study and know there is no hidden motive of which I have not been informed.

IHAVE CAREFULLY STUDIED THE ABOVE AND UNDERSTAND THIS AGREEMENT. I FREELY CONSENT AND AGREE TO PARTICIPATE IN THIS STUDY.

NAME (please print) ____

SIGNATURE ____

WITNESS SIGNATURE ____

DATE ______________________

Appendix B2

CONSENT FORM TO PARTICIPATE IN RESEARCH

This is to state that I agree to participate in a program of research being conducted by Caroline van de Velde of the Department of Psychology at Concordia University, in conjunction with her Master's Thesis project, under the supervision of Dr. Michael von Grunau.

A. PURPOSE

I have been informed that the purpose of the research is to investigate how the brain processes visual information and it's interaction with language. This is being conducted to partially fulfill the requirements for a Master's Thesis.

B. PROCEDURES

I have been informed that the experiment involves the following procedures: Three pictures of objects will be shown side by side in the center of the computer screen. Shortly after, the name of one of the three objects will be uttered through the headphones. My task will be to indicate which of the three pictures corresponds to the object just heard. If you believe the object to be the first picture on the left, then you press the left most button on the button box, if you believe it to be the center picture, then you press the center button, and finally if you believe it to be the right most picture then you press the right button. The completion of the experiment will take about 10 minutes. I have been informed that my name will not be associated with my data in the experiment. I understand that my participation in the experiment, and the information and data I provide, will be kept strictly confidential. I understand that if the results are published, individual data will be reported but I will be only indicated as "Subject" and then a number.

C. CONDITIONS OF PARTICIPATION

- I understand that I am free to decline to participate in the experiment without negative consequences.
- I understand that I am free to withdraw my consent and discontinue my participation at anytime without negative consequences.
- I understand that my participation in this study is confidential (i.e., the researcher will know, but my identity will not be disclosed).
- I understand that my data from this research may be published.
- I understand the purpose of this study and know there is no hidden motive of which I have not been informed.

IHAVE CAREFULLY STUDIED THE ABOVE AND UNDERSTAND THIS AGREEMENT. I FREELY CONSENT AND AGREE TO PARTICIPATE IN THIS STUDY.

NAME (please print) ______________________________

SIGNATURE ______________________________

WITNESS SIGNATURE ______________________________

DATE ________________

Appendix B3

CONSENT FORM TO PARTICIPATE IN RESEARCH

This is to state that I agree to participate in a program of research being conducted by Caroline van de Velde of the Department of Psychology at Concordia University, in conjunction with her Master's Thesis project, under the supervision of Dr. Michael von Grunau.

A. PURPOSE

I have been informed that the purpose of the research is to investigate how the brain processes visual information and it's interaction with language. This is being conducted to partially fulfill the requirements for a Master's Thesis.

B. PROCEDURES

I have been informed that the experiment involves the following procedures: An eye-tracker machine will be placed over my head that will record my eye movements as I look at pictures of objects on a computer screen. I will also hear word through headphones. A central dot will be present, when it is red I am not allowed to move my eyes but must keep fixated on the red dot, when it is green it means I am free to move my eyes. A set of six pictures will be shown briefly on the screen. My task will be to scan each object before they disappear. When the objects reappear, my task will be to look at the picture of the object just heard through the headphones. In order to initiate each trial I will be required to press the yellow key on the button box.

The completion of the experiment will take about 15 minutes. I have been informed that my name will not be associated with my data in the experiment. I understand that my participation in the experiment, and the information and data I provide, will be kept strictly confidential. I understand that if the results are published, individual data will be reported but I will be only indicated as "Subject" and then a number.

C. CONDITIONS OF PARTICIPATION

- I understand that I am free to decline to participate in the experiment without negative consequences.
- I understand that I am free to withdraw my consent and discontinue my participation at anytime without negative consequences.
- I understand that my participation in this study is confidential (i.e., the researcher will know, but my identity will not be disclosed).
- I understand that my data from this research may be published.
- I understand the purpose of this study and know there is no hidden motive of which I have not been informed.

IHAVE CAREFULLY STUDIED THE ABOVE AND UNDERSTAND THIS AGREEMENT. I FREELY CONSENT AND AGREE TO PARTICIPATE IN THIS STUDY.

NAME (please print) ____

SIGNATURE ____

WITNESS SIGNATURE ____________________________________

DATE ______________________

Appendix B4

CONSENT FORM TO PARTICIPATE IN RESEARCH

This is to state that I agree to participate in a program of research being conducted by Caroline van de Velde of the Department of Psychology at Concordia University, in conjunction with her Master's Thesis project, under the supervision of Dr. Michael von Grunau.

A. PURPOSE

I have been informed that the purpose of the research is to investigate how the brain processes visual information and it's interaction with language. This is being conducted to partially fulfill the requirements for a Master's Thesis.

B. PROCEDURES

I have been informed that the experiment involves the following procedures: An eye-tracker machine will be placed over my head that will record my eye movements as I look at pictures of objects on a computer screen. I will also hear word through headphones. A central dot will be present, when it is red I am not allowed to move my eyes but must keep fixated on the red dot, when it is green it means I am free to move my eyes. A set of six pictures will be shown on the screen and my task will be to look at the picture of the object just heard through the headphones. In order to initiate each trial I will be required to press the yellow key on the button box.

The completion of the experiment will take about 30 minutes. I have been informed that my name will not be associated with my data in the experiment. I understand that my participation in the experiment, and the information and data I provide, will be kept strictly confidential. I understand that if the results are published, individual data will be reported but I will be only indicated as "Subject" and then a number.

C. CONDITIONS OF PARTICIPATION

- I understand that I am free to decline to participate in the experiment without negative consequences.
- I understand that I am free to withdraw my consent and discontinue my participation at anytime without negative consequences.
- I understand that my participation in this study is confidential (i.e., the researcher will know, but my identity will not be disclosed).
- I understand that my data from this research may be published.
- I understand the purpose of this study and know there is no hidden motive of which I have not been informed.

IHAVE CAREFULLY STUDIED THE ABOVE AND UNDERSTAND THIS AGREEMENT. I FREELY CONSENT AND AGREE TO PARTICIPATE IN THIS STUDY.

NAME (please print) ______________________________

SIGNATURE ______________________________

WITNESS SIGNATURE ______________________________

DATE ________________

Appendix B5

CONSENT FORM TO PARTICIPATE IN RESEARCH

This is to state that I agree to participate in a program of research being conducted by Caroline van de Velde of the Department of Psychology at Concordia University, in conjunction with her Master's Thesis project, under the supervision of Dr. Michael von Grunau.

A. PURPOSE

I have been informed that the purpose of the research is to investigate how the brain processes visual information and it's interaction with language. This is being conducted to partially fulfill the requirements for a Master's Thesis.

B. PROCEDURES

I have been informed that the experiment involves the following procedures: An eye-tracker machine will be placed over my head that will record my eye movements as I look at pictures of objects on a computer screen. I will also hear sentences through headphones. A central dot will be present, when it is red I am not allowed to move my eyes but must keep fixated on the red dot, when it is green it means I am free to move my eyes. A set of six pictures will appear briefly on the screen and my task will be to scan each one until they disappear. When the objects reappear, my task will be to indicate whether the picture of the object uttered in the sentence is present (green key if present, red key if not present) and to look at the pictures of the object if it is present before responding. In order to initiate each trial I will be required to press the yellow key on the button box.

The completion of the experiment will take about 30 minutes. I have been informed that my name will not be associated with my data in the experiment. I understand that my participation in the experiment, and the information and data I provide, will be kept strictly confidential. I understand that if the results are published, individual data will be reported but I will be only indicated as "Subject" and then a number.

C. CONDITIONS OF PARTICIPATION

- I understand that I am free to decline to participate in the experiment without negative consequences.
- I understand that I am free to withdraw my consent and discontinue my participation at anytime without negative consequences.
- I understand that my participation in this study is confidential (i.e., the researcher will know, but my identity will not be disclosed).
- I understand that my data from this research may be published.
- I understand the purpose of this study and know there is no hidden motive of which I have not been informed.

IHAVE CAREFULLY STUDIED THE ABOVE AND UNDERSTAND THIS AGREEMENT. I FREELY CONSENT AND AGREE TO PARTICIPATE IN THIS STUDY.

NAME (please print) ____

SIGNATURE ____

WITNESS SIGNATURE ____

DATE ______________________

Appendix B6

CONSENT FORM TO PARTICIPATE IN RESEARCH

This is to state that I agree to participate in a program of research being conducted by Caroline van de Velde of the Department of Psychology at Concordia University, in conjunction with her Master's Thesis project, under the supervision of Dr. Michael von Grunau.

A. PURPOSE

I have been informed that the purpose of the research is to investigate how the brain processes visual information and it's interaction with language. This is being conducted to partially fulfill the requirements for a Master's Thesis.

B. PROCEDURES

I have been informed that the experiment involves the following procedures: An eye-tracker machine will be placed over my head that will record my eye movements as I look at pictures of objects on a computer screen. I will also hear sentences through headphones. A central dot will be present, when it is red I am not allowed to move my eyes but must keep fixated on the red dot, when it is green it means I am free to move my eyes. A set of six pictures of objects will appear on the screen, and my task will be to indicate whether the picture of the object uttered in the sentence is present (green key if present, red key if not present) and to look at the pictures of the object if it is present before responding. In order to initiate each trial I will be required to press the yellow key on the button box.

The completion of the experiment will take about 30 minutes. I have been informed that my name will not be associated with my data in the experiment. I understand that my participation in the experiment, and the information and data I provide, will be kept strictly confidential. I understand that if the results are published, individual data will be reported but I will be only indicated as "Subject" and then a number.

C. CONDITIONS OF PARTICIPATION

- I understand that I am free to decline to participate in the experiment without negative consequences.
- I understand that I am free to withdraw my consent and discontinue my participation at anytime without negative consequences.
- I understand that my participation in this study is confidential (i.e., the researcher will know, but my identity will not be disclosed).
- I understand that my data from this research may be published.
- I understand the purpose of this study and know there is no hidden motive of which I have not been informed.

IHAVE CAREFULLY STUDIED THE ABOVE AND UNDERSTAND THIS AGREEMENT. I FREELY CONSENT AND AGREE TO PARTICIPATE IN THIS STUDY.

NAME (please print) ____

SIGNATURE ____

WITNESS SIGNATURE ______________________________________

DATE ______________________

Appendix C

Instructions for Experiment 1, 2, 3, 4 & 5

Appendix C1

Instructions for Experiment 1a

In this experiment you will see a sequence of pictures of objects flashing on the screen. Your task is to say the name of each object as fast as you can. So, for instance, if you see a picture of a tree on the screen you should say "tree" as fast as you can. It is important that you name the object as fast and as accurate as you can. It is also important that you say the name of the object as clear as possible so that the microphone can signal your response to the computer. As soon as the computer records your response you will hear a beep. If you don't hear a beep, this means that the computer was not able to record your response. In any case, you should go ahead as a new picture will appear on the screen. Before each picture you will see an asterisk (*). This is the location on the screen where the picture will appear. Try to look at that location at all times so that you don't miss a picture when it flashes on the screen. This experiment should take only a couple of minutes. Press a button when you are ready to begin the practice trials.

Appendix C2

Reinforce Instructions

This is the end of the practice trials. Remember to say the word as quickly and as clearly as possible. You should hear a beep after each picture. If you don't hear a beep, this means that you either (a) are not close enough to the microphone or (b) are not saying the word fast or clear enough. Have fun!. Press a button when you are ready to continue.

Appendix C3

Instructions for Experiment 1b

In this experiment you will see 3 pictures of objects on the screen. You will also hear the name of one of the objects on the screen. Your task is to choose, as fast as you can, which of the 3 pictures of objects refers to the word just heard. If you believe the answer to be the left picture, then you press the red button on the button box. If you believe the answer to be the center picture, then you press the yellow button. If you believe the answer to be the right picture, then you press the green button. It is important that you press the button to the proper object as fast and as accurate as you can. This experiment should take only a couple of minutes. Press any button when you are ready to begin the practice trials.

Appendix C4

Reinforce Instructions

This is the end of the practice trials, you will now start the real experiment. Press any button to begin.

Appendix C5

Instructions for Experiment 2

In this experiment you will see several pictures of objects displayed on the screen. At a certain point you will hear a sentence that refers to one of the objects. Your task will be to look at the object that the sentence refers to as quickly as possible.

There are several events before you get the sentence that matches the object. Please read carefully the sequence of events and what you should do in each part of the experimental trials.

1- First, each trial will start with an asterisk (*) displayed in the middle of the screen. You should keep your eyes on this asterisk and press the YELLOW key when you are ready to begin the new trial.

2- Second, you will see a set of 6 pictures of objects presented on the screen. The first time these pictures appear you will also see a GREEN dot where the asterisk was displayed. The GREEN dot means that you are FREE to move your eyes and look at all the pictures displayed on the screen. At this point it is important that you look at all of the pictures because you will be required to remember one of the pictures of the display.

3- A couple of seconds after the GREEN dot will turn RED and the pictures will disappear. This means that you should immediately look at the center for the screen again, that is, that you should look at the RED dot. In order to help you notice that the dot went from green to red, you will hear a beep. Remember, at the beep the dot turns RED and you should look at it until it turns green again.

4- A couple of seconds after the dot turns RED, you will hear a sentence. Shortly after, the RED dot will turn GREEN, and the pictures will reappear. Your task is to move your eyes to the object that the sentence refers to.

5- Once you have looked at the object, you press the RED key if the object mentioned in the sentence is NOT PRESENT and press the GREEN key if the object is PRESENT. This will also start a new trial.

Appendix C6

<u>Reinforce Instructions</u>

So, to sum up, here's the sequence of events:

1-you see the asterisk, you press the YELLOW key to start a trial

2-you keep your eyes on the RED dot in the center of the screen

3-shortly after you will hear a sentence and then the RED dot will turn GREEN and 6 pictures of objects will appear on the screen.
your task is to look at the picture of the object mentioned in the sentence.

4-once you have looked directly at the object, press the RED key if the object mentioned in the sentence is NOT PRESENT and press the GREEN key if the object is PRESENT. This will also move you to the next trial.

Here are a couple of important things to remember:

-GREEN means MOVE YOUR EYES (to the object that the sentence names)

-RED means DON'T MOVE YOUR EYES and look at the dot

-When you are free to move, after you heard the sentence, look at the object immediately and only press the RED or GREEN key to move to the next trial once you have looked at the object

Appendix C7

Instructions for Experiment 3

In this experiment you will see several pictures of objects displayed on the screen. At a certain point you will hear a word that refers to one of the objects. Your task will be to look at the object that the word refers to as quickly as possible.
There are several events before you get the word that matches the object. Please read carefully the sequence of events and what you should do in each part of the experimental trials.

1- First, each trial will start with an asterisk (*) displayed in the middle of the screen. You should keep your eyes on this asterisk and press the YELLOW key when you are ready to begin the new trial.

2- A RED dot will appear at the center of the screen. You must stare at it until it turns green. It is important that you do not move your eyes while the dot is RED.

3- A couple of seconds after the red dot, you will hear a word through the headphones.

4- Shortly after, the red dot will turn GREEN and pictures of objects will appear on the screen. Your task is to move your eyes to the picture of the object you just heard.

5- When you find the picture of the object you just heard press the GREEN key.

6- It is important that you look at the object when pressing the GREEN key.

7- Once you respond it will bring you to the next trial.

Appendix C8

Reinforce Instructions

So, to sum up, here's the sequence of events:

1-you see the asterisk, you press the YELLOW key to start a new trial.

2-you will see a RED dot, you must stare at it until it turns green.

3-you will hear a word through the headphones.

4-shortly after, the red dot will turn GREEN and pictures of objects will appear on the screen.

5-your task will be to find the picture of the object that you just heard.

6-when you find the picture of the object you just heard press the GREEN key.

7-it is important that you look at the object when you press the GREEN key.

Here are a couple of important things to remember:

-RED means DO NOT MOVE YOUR EYES

-GREEN means MOVE YOUR EYES

-Look at the object when you press the GREEN key

Appendix C9

<u>Instructions for Experiment 4</u>

In this experiment you will see several pictures of objects displayed on the screen. At a certain point you will hear a sentence that refers to one of the objects. Your task will be to look at the object that the sentence refers to as quickly as possible.

There are several events before you get the sentence that matches the object. Please read carefully the sequence of events and what you should do in each part of the experimental trials.

1- First, each trial will start with an asterisk (*) displayed in the middle of the screen. You should keep your eyes on this asterisk and press the YELLOW key when you are ready to begin the new trial.

2- You will see a RED dot in the center of the screen, you must keep your eyes on this dot.

3- A couple of seconds after you will hear a sentence. Shortly after, the RED dot will turn GREEN, and 6 pictures of objects will appear on the screen. Your task is to move your eyes to the object that the sentence refers to.

4- Once you have looked at the object, you press the RED key if the object mentioned in the sentence is NOT PRESENT and press the GREEN key if the object is PRESENT. This will also start a new trial.

Appendix C10

Reinforce Instructions

So, to sum up, here's the sequence of events:

1-you see the asterisk, you press the YELLOW key to start a new trial.

2-you will see a RED dot, you must stare at it until it turns green.

3-you will hear a word through the headphones.

4-shortly after, the red dot will turn GREEN and pictures of objects will appear on the screen.

5-your task will be to find the picture of the object that you just heard.

6-when you find the picture of the object you just heard press the GREEN key.

7-it is important that you look at the object when you press the GREEN key.

Here are a couple of important things to remember:

-RED means DO NOT MOVE YOUR EYES

-GREEN means MOVE YOUR EYES

-look at the object when you press the GREEN key

Appendix C11

Instructions for Experiment 5

In this experiment you will see several pictures of objects displayed on the screen. At a certain point you will hear a sentence that refers to one of the objects.
Your task will be to look at the object that the sentence refers to as quickly as possible.
There are several events before you get the sentence that matches the object. Please read carefully the sequence of events and what you should do in each part of the experimental trials.

1- First, each trial will start with an asterisk (*) displayed in the middle of the screen. You should keep your eyes on this asterisk and press the YELLOW key when you are ready to begin the new trial.

2- You will see a RED dot in the center of the screen, you must keep your eyes on this dot.

3- A couple of seconds after you will hear a sentence. Shortly after, the RED dot will turn GREEN, and 6 pictures of objects will appear on the screen. Your task is to move your eyes to the object that the sentence refers to.

4- Once you have looked at the object, you press the RED key if the object mentioned in the sentence is NOT PRESENT and press the GREEN key if the object is PRESENT. This will also start a new trial.

Appendix C12

Reinforce Instructions

So, to sum up, here's the sequence of events:

1-you see the asterisk, you press the YELLOW key to start a trial

2-you keep your eyes on the RED dot in the center of the screen

3-shortly after you will hear a sentence and then the RED dot will turn GREEN and 6 pictures of objects will appear on the screen. Your task is to look at the picture of the object mentioned in the sentence.

4-once you have looked directly at the object, press the RED key if the object mentioned in the sentence is NOT PRESENT and press the GREEN key if the object is PRESENT. This will also move you to the next trial.

Here are a couple of important things to remember:

-GREEN means MOVE YOUR EYES (to the object that the sentence names)

-RED means DON'T MOVE YOUR EYES and look at the dot

-When you are free to move, after you heard the sentence, look at the object immediately and only press the RED or GREEN key to move to the next trial once you have looked at the object

Appendix D

ANOVA and Tukey Post-Hoc Comparisons for

Experiments 1, 2, 3, 4, & 5

Table 1

ANOVA Summary Table for Reaction Time as a Function of Categories in Naming Task.

Source	SS	df	MS	F
Between-Subjects				
Categories	147.50	5	29.50	0.801
Error	884.00	24	36.83	

Table 2

ANOVA Summary Table for Average Saccade Onset to target Object, as a Function of Probe Points, for Words in Isolation, in Memory Matching Task.

Source	SS	df	MS	F
Within-Subjects				
Probe Points	415475.37	2	207737.68	20.37****
Error	198555.34	8	24819.42	

****p<.0001

Average Saccade Onset by Probe Point Conditions

Source	Onset	Offset	Offset+200
Probe Points	745.19_a	523.32_b	454.47_b

Note. Means in the same row that do not share subscripts differ at $p < .05$ in the Tukey pairwise comparison.

Table 3

ANOVA Summary Table for Saccade Onset Per Item, as a Function of Probe Points, for Words in Isolation, in Memory Matching Task.

Source	SS	df	MS	F
Within-Subjects				
Probe Point	894578.04	2	447289.02	23.89****
Error	718545.30	23	31241.10	

****$p<.0001$

Saccade Onset Per Item by Probe Point Conditions

Source	Onset	Offset	Offset+200
Probe Points	732.66_a	545.77_b	466.83_b

Note. Means in the same row that do not share subscripts differ at $p < .05$ in the Tukey pairwise comparison.

Table 4

ANOVA Summary Table for First Saccade Onset to Target Object, as a Function of Probe Points, for Words in Isolation, in Memory Matching Task.

Source	SS	df	MS	F
Within-Subjects				
Probe Point	167311.76	2	83655.88	14.87**
Error	309170.79	4	77292.70	

**$p<.01$

First Saccade Onset by Probe Point Conditions

Source	Onset	Offset	Offset+200
Probe Points	514.65_a	335.72_b	263.38_b

Note. Means in the same row that do not share subscripts differ at $p < .05$ in the Tukey pairwise comparison.

Table 5

ANOVA Summary Table for Percent Correct Responses, as a Function of Probe Points, for Words in Isolation, in Memory Matching Task.

Source	SS	df	MS	F
Within-Subjects				
Probe Points	1539.35	2	769.68	3.60
Error	2546.30	8	318.29	

Table 6

ANOVA Summary Table for Percent Responses, as a Function of Type of Competitor and Probe Point, for words in Isolation, in Memory Matching Task.

Source	SS	df	MS	F
Within-Subjects				
Competitor Type (C)	723.24	4	180.81	1.34
Probe Point (P)	955.56	2	477.78	10.11**
C x P	3003.01	8	375.38	2.54*
Error	1201.95	8	150.24	

**p<.01, *p<.05

Table 7

ANOVA Summary Table for First Saccade to an Object, as a Function of Probe Point, with Words in Isolation, in Memory Matching Task.

Source	SS	df	MS	F
Within-Subjects				
Probe Point	357141.78	2	178570.89	13.27****
Error	1155232.28	53	21796.84	

****p<.0001

Saccade Onset to an Object by Probe Point Conditions

Source	Onset	Offset	Offset+200
Probe Points	414.13_a	333.80_b	302.69_b

Note. Means in the same row that do not share subscripts differ at $p < .05$ in the Tukey pairwise comparison.

Table 8

ANOVA Summary Table for Average Saccade Onset to target Object, as a Function of Probe Points, for Words in Isolation, in Visual Search Task.

Source	SS	df	MS	F
Within-Subjects				
Probe Points	74164.89	2	37082.44	4.16*
Error	669275.83	8	83659.48	

*p<.05

Table 9

ANOVA Summary Table for Saccade Onset Per Item, as a Function of Probe Points, for Words in Isolation, in Visual Search Task.

Source	SS	df	MS	F
Within-Subjects				
Probe Point	375301.83	2	187650.92	6.76**
Error	1291851.98	23	56167.48	

**$p < .01$

Saccade Onset Per Item by Probe Point Conditions

Source	Onset	Offset	Offset+200
Probe Points	921.52_a	746.87_b	810.14_b

Note. Means in the same row that do not share subscripts differ at $p < .05$ in the Tukey pairwise comparison.

Table 10

ANOVA Summary Table for First Saccade Onset to Target Object, as a Function of Probe Points, for Words in Isolation, in Visual Search Task.

Source	SS	df	MS	F
Within-Subjects				
Probe Point	31423.13	2	15711.56	3.18
Error	237676.92	4	59419.23	

Table 11

ANOVA Summary Table for Percent Correct Responses, as a Function of Probe Points, for Words in Isolation, in Visual Search Task.

Source	SS	df	MS	F
Within-Subjects				
Probe Points	34.72	2	17.36	0.073
Error	4062.50	8	507.81	

Table 12

ANOVA Summary Table for Percent Responses, as a Function of Type of Competitor and Probe Point, for words in Isolation, in Visual Search Task.

Source	SS	df	MS	F
Within-Subjects				
Competitor Type (C)	76.39	4	19.10	0.120
Probe Point (P)	16.20	2	8.102	0.138
C x P	2958.33	8	369.79	2.79*
Error	780.09	8	97.51	

*$p < .05$

Table 13

ANOVA Summary Table for First Saccade to an Object, as a Function of Probe Point, with Words in Isolation, in Visual Search Task.

Source	SS	df	MS	F
Within-Subjects				
Probe Point	192071.65	2	96035.83	6.99**
Error	3941653.42	60	65694.22	

**$p<.01$

Saccade Onset to an Object by Probe Point Conditions

Source	Onset	Offset	Offset+200
Probe Points	489.67_a	416.39_b	426.66_b

Note. Means in the same row that do not share subscripts differ at $p < .05$ in the Tukey pairwise comparison.

Table 14

ANOVA Summary Table for Average Saccade Onset to target Object, as a Function of Tasks, and Probe Points, for Words in Isolation.

Source	SS	df	MS	$\underline{F}$
Within-Subjects				
Task (T)	987051.43	1	987051.43	22.24**
Probe Points (P)	369626.34	2	184813.17	18.28****
T x P	120013.92	2	600006.96	6.67**
Error	512689.86	8	64086.23	

****p<.0001, **p<.01

Average Saccade Onset by Probe Point Conditions

Source	Onset	Offset	Offset+200
Probe Points	826.53_a	651.42_b	650.62_b

Note. Means in the same row that do not share subscripts differ at $p < .05$ in the Tukey pairwise comparison.

Table 15

ANOVA Summary Table for First Saccade Onset to Target Object, as a Function of Tasks, and Probe Points, for Words in Isolation.

Source	SS	df	MS	F
Within-Subjects				
Task (T)	240289.60	1	240289.60	14.65*
Probe Point (P)	199817.74	2	99908.87	26.30***
T x P	19254.47	2	9627.24	0.647
Error	416378.06	4	104094.52	

***$p<.001$, *$p<.05$

First Saccade Onset by Probe Point Conditions

Source	Onset	Offset	Offset+200
Probe Points	595.81_a	436.84_b	421.18_b

Note. Means in the same row that do not share subscripts differ at $p < .05$ in the Tukey pairwise comparison.

Table 16

ANOVA Summary Table for Percent Correct Responses, as a Function of Tasks, and Probe Points, for Words in Isolation.

Source	SS	df	MS	F
Within-Subjects				
Task (T)	740.74	1	740.74	2.86
Probe Points (P)	561.34	2	280.67	1.25
T x P	1012.73	2	506.37	2.21
Error	4537.04	8	567.13	

Table 17

ANOVA Summary Table for Average Saccade Onset to target Object, as a Function of Verb Type and Probe Points, for Words in Sentences, in Memory Matching Task.

Source	SS	df	MS	F
Within-Subjects				
Verb Type (V)	118.09	1	118.09	0.002
Probe Points (P)	378822.96	2	189411.48	6.80**
V x P	2504.28	2	1252.14	0.054
Error	1118630.22	16	69914.39	

**$p<.01$

Average Saccade Onset by Probe Point Conditions

Source	Onset	Offset	Offset+200
Probe Points	598.79_a	494.86_b	448.77_b

Note. Means in the same row that do not share subscripts differ at $p < .05$ in the Tukey pairwise comparison.

Table 18

ANOVA Summary Table for Saccade Onset Per Item, as a Function of Verb Type, and Probe Points, for Words in Sentences, in Memory Matching Task.

Source	SS	df	MS	F
Within-Subjects				
Verb Type (V)	3990.03	1	3990.03	0.145
Probe Point (P)	581271.41	2	290635.70	5.40**
V x P	62598.17	2	31299.08	0.918
Error	2204600.50	23	95852.20	

**p<.01

Saccade Onset Per Item by Probe Point Conditions

Source	Onset	Offset	Offset+200
Probe Points	601.17_a	509.92_b	452.12_b

Note. Means in the same row that do not share subscripts differ at $p < .05$ in the Tukey pairwise comparison.

Table 19

ANOVA Summary Table for First Saccade Onset to Target Object, as a Function of Verb Type, and Probe Points, for Words in Sentences, in Memory Matching Task.

Source	SS	df	MS	F
Within-Subjects				
Verb Type (V)	32329.89	1	32329.89	0.372
Probe Point (P)	89309.75	2	44654.87	3.23
V x P	13493.45	2	6746.72	0.635
Error	130323.14	4	32580.79	

Table 20

ANOVA Summary Table for Percent Correct Responses, as a Function of Verb Type, and Probe Points, for Words in Sentences, in Memory Matching Task.

Source	SS	df	MS	F
Within-Subjects				
Verb Type (V)	700.23	1	700.23	1.42
Probe Points (P)	1805.56	2	902.78	2.095
V x P	46.296	2	23.148	0.038
Error	11927.08	17	701.59	

Table 21

ANOVA Summary Table for Percent Responses, as a Function of Type of Competitor and Probe Point, for Words in Sentences with Causative Verbs, in Memory Matching Task.

Source	SS	df	MS	F
Within-Subjects				
Competitor Type (C)	1223.21	4	305.80	1.78
Probe Point (P)	912.62	2	456.31	2.37
C x P	1373.64	8	171.71	0.677
Error	4355.07	17	256.18	

Table 22

ANOVA Summary Table for Percent Responses, as a Function of Type of Competitor and Probe Point, for Words in Sentences with Perception Verbs, in Memory Matching Task.

Source	SS	df	MS	F
Within-Subjects				
Competitor Type (C)	1259.26	4	314.82	1.63
Probe Point (P)	1004.63	2	502.32	4.10*
C x P	1101.85	8	137.73	0.517
Error	3844.91	17	226.17	

*$p < .05$

Table 23

ANOVA Summary Table for First Saccade to an Object, as a Function of Verb Type and Probe Point, with Words in Sentences, in Memory Matching Task.

Source	SS	df	MS	F
Within-Subjects				
Verb Type (V)	77478.99	1	77478.99	11.50**
Probe Point (P)	407939.27	2	203969.64	16.42****
V x P	22127.92	2	11063.96	0.949
Error	914321.18	37	24711.38	

****$p<.0001$, **$p<.01$

Saccade Onset to an Object by Probe Point Conditions

Source	Onset	Offset	Offset+200
Probe Points	329.74_a	240.58_b	217.24_b

Note. Means in the same row that do not share subscripts differ at $p < .05$ in the Tukey pairwise comparison.

Table 24

ANOVA Summary Table for Pure Verb Effects by Probe Point, in Memory Matching Task.

Source	SS	df	MS	F
Within-Subjects				
Verb Type (V)	2233.71	1	2233.71	0.075
Probe Point (P)	338844.42	2	169422.21	1.946
V x P	97158.69	2	48579.35	1.807
Error	1857925.74	21	88472.65	

Table 25

ANOVA Summary Table for Average Saccade Onset to target Object, as a Function of Verb Type, and Probe Points, for Words in Sentences, in Visual Search Task.

Source	SS	df	MS	*F*
Within-Subjects				
Verb Type (V)	4213.02	1	4213.02	0.177
Probe Points (P)	32120.57	2	16060.28	0.388
V x P	27246.09	2	13623.05	0.373
Error	497138.70	12	41428.23	

Table 26

ANOVA Summary Table for Saccade Onset Per Item, as a Function of Verb Type, and Probe Points, for Words in Sentences, in Visual Search Task.

Source	SS	df	MS	F
Within-Subjects				
Verb Type (V)	13134.88	1	13134.88	0.392
Probe Point (P)	92182.98	2	46091.49	1.385
V x P	26512.94	2	13256.47	0.595
Error	1359998.38	22	61818.11	

Table 27

ANOVA Summary Table for Percent Correct Responses, as a Function of Verb Type and Probe Points, for Words in Sentences, in Visual Search Task.

Source	SS	df	MS	F
Within-Subjects				
Verb Type (V)	23.15	1	23.15	0.076
Probe Points (P)	1493.06	2	746.53	1.23
V x P	567.13	2	283.57	0.431
Error	18333.33	17	1078.43	

Table 28

ANOVA Summary Table for Percent Responses, as a Function of Type of Competitor and Probe Point, for Words in Sentences with Causative Verbs, in Visual Search Task.

Source	SS	df	MS	F
Within-Subjects				
Competitor Type (C)	2000.00	4	500.00	2.00
Probe Point (P)	97.22	2	48.61	0.288
C x P	3166.67	8	395.83	1.33
Error	916.67	17	53.92	

Table 29

ANOVA Summary Table for Percent Responses, as a Function of Type of Competitor and Probe Point, for Words in Sentences with Perception Verbs, in Visual Search Task.

Source	SS	df	MS	F
Within-Subjects				
Competitor Type (C)	402.78	4	100.69	0.335
Probe Point (P)	32.407	2	16.204	0.077
C x P	5013.89	8	626.736	2.358*
Error	1768.52	17	104.03	

*$p < .05$

Table 30

ANOVA Summary Table for First Saccade to an Object, as a Function of Verb Type and Probe Point, with Words in Sentences, in Visual Search Task.

Source	SS	df	MS	F
Within-Subjects				
Verb Type (V)	2229.45	1	2229.45	0.164
Probe Point (P)	1852500.46	2	426250.23	19.89****
V x P	63100.38	2	31550.19	2.134
Error	3404852.65	52	65477.94	

****$p<.0001$

Saccade Onset to an Object by Probe Point Conditions

Source	Onset	Offset	Offset+200
Probe Points	371.35_a	278.18_b	289.44_b

Note. Means in the same row that do not share subscripts differ at $p < .05$ in the Tukey pairwise comparison.

Table 31

ANOVA Summary Table for Pure Verb Effects by Probe Point, in Visual Search Task.

Source	SS	df	MS	F
Within-Subjects				
Verb Type (V)	3669.59	1	3669.59	0.076
Probe Point (P)	317692.45	2	158846.22	2.019
V x P	37076.01	2	18538.00	0.494
Error	1560346.85	22	70924.86	

Table 32

ANOVA Summary Table for Average Saccade Onset to target Object, as a Function of Tasks, and Probe Points, for Words in Sentences.

Source	SS	df	MS	F
Within-Subjects				
Task (T)	1047781.44	1	1047781.44	26.67****
Probe Points (P)	465565.97	2	232782.99	9.089***
T x P	31379.89	2	15689.94	0.687
Error	1729616.31	31	55794.08	

****$p<.0001$, ***$p<.001$

Average Saccade Onset by Probe Point Conditions

Source	Onset	Offset	Offset+200
Probe Points	513.33_a	427.22_b	390.48_b

Note. Means in the same row that do not share subscripts differ at $p < .05$ in the Tukey pairwise comparison.

Table 33

ANOVA Summary Table for Percent Correct Responses, as a Function of Tasks, and Probe Points, for Words in Isolation.

Source	SS	df	MS	F
Within-Subjects				
Task (T)	1276.04	1	1276.04	1.75
Probe Points (P)	3177.08	2	1588.54	2.21
T x P	121.528	2	60.764	0.150
Error	19036.46	35	543.899	