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Eye Movements as an Index of Linguistic Processing in Language Production

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Researchers have recently turned to eye tracking to study the complex cognitive processes underlying speech production. The present paper provides a brief overview of studies of sentence production and eye movements. A review then follows of research using eye tracking to investigate eye movements during multiple object naming and differences between findings in reading research. The majority of these studies attempt to determine the extent to which object naming can happen in serial or parallel. Lastly, I provide a brief comparison between seriality and parallelism in reading and multiple object naming.

With the use of eye trackers, researchers have been able to discover a vast wealth of knowledge about the way the human mind functions. Where the eyes fixate is highly determined by attention allocation, and how long the eyes linger in a location is influenced by the amount of cognitive processing required there (Rayner, 1998). For the most part, these advances have been made in the scene perception, visual search and language comprehension domains. Recently, researchers in the field of language production have turned to eye tracking paradigms to reveal the complex cognitive processes underlying language production, which have traditionally been more difficult to study than language comprehension. This is, in part, due to the nature of the behavior, in that information flows in the opposite direction in language production as it does in comprehension.

Speech production begins with abstract semantic representations and proceeds through the following stages: (1) the lexical representations of the individual words in the sentence must be selected, (2) then the sublexical representations (sounds of those words) must be activated, and (3) the sounds must be articulated. Because speech is internally generated, experimenters traditionally have found it difficult to manipulate what speakers say. This has changed within the past decade with the use of eye trackers and eye tracking methodologies, which have traditionally been used to study reading (see Rayner, 1998, 2009 for a review) and speech perception (Dahan, Magnuson, & Tanenhaus, 2001; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995). Now eye tracking allows language production researchers to present visual stimuli to be produced while (1) monitoring eye movements as speakers describe the scene and (2) manipulating the display as speakers are looking at it (Griffin, 2004; Meyer, 2004).

Eye Movements as a Window into Cognitive Processing during Language Production

Studies of whole sentence production have revealed that speakers fixate the referents of their utterances less than a second before they speak about them and do so in the same order in which they mention them (Griffin & Bock, 2000). Griffin and Bock reported no influence of the order of fixation on the order of mention of objects in the scene (e.g., agents of the sentence were uttered first regardless of whether they were fixated first before or after the patient) suggesting that speakers first apprehend what is occurring in the scene and then move their eyes around the scene in an order determined by their intended utterance. However, Griffin and Bock did not directly manipulate order of fixation; they manipulated whether the agent was on the left or right side of the scene, exploiting the fact that English readers might have a tendency to view a scene

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from left to right. Gleitman, January, Nappa and Trueswell (2007), on the other hand, manipulated which object was fixated first using an attention capture paradigm (an imperceptible flicker that drove eye movements toward a particular location on the computer screen). They found that subjects tended to start speaking about the object they fixated first, regardless of whether that utterance resulted in a dispreferred linguistic structure (e.g., the passive construction as compared to the active construction). These data support the ideas that speakers (1) prepare speech incrementally and (2) select words and structures based on accessibility of lexico-semantic items (Bock, 1982, 1986).

Eye movements may be used to investigate cognitive processing that is obscured or completely untapped by measures of speech onset latency. When speaking about visually presented stimuli, the alignment of eye gaze and speech are very tight. Gaze durations (defined as the time spent viewing an object before leaving it for the first time) in object naming tasks are generally much longer (approximately 500–900ms) than those in silent reading tasks (approximately 250–350ms), in part because there is the added need to access phonetic codes in order to overtly produce speech. Therefore, there are more and longer fixations on an object in multiple object naming than there are on a word in silent reading. Indeed, when an overt speech response in reading is required (e.g., when reading aloud) gaze durations are longer (though not as long as in object naming) and the number of fixations is higher than in silent reading (Rayner, 1998, 2009).

The amount of time spent looking at an object until that object is named is approximately 900ms (Griffin & Bock, 2000) and the eyes generally move to the next object shortly before naming the current object (Meyer, 2004; Meyer & Dobel, 2003; Van der Meulen, Meyer, & Levelt, 2001). Objects are rarely skipped when being named (van der Meulen et al., 2001) as opposed to words in reading, where approximately a third of the words in the text are skipped (Rayner, 1998, 2009). Although objects in these tasks are typically larger than words in text, they are generally presented at further eccentricities and are therefore hard to identify due to acuity limitations. Furthermore, as mentioned before, being tied to speech output slows the eyes down, and fixating each to-be-named object may be a prudent way to keep the timing of the eyes closer to the timing of the voice. Indeed, skipping rates in object naming tasks can be increased by making the objects more predictable (i.e., by repeating the same object in the same location) though not by very much (van der Meulen et al., 2001).

Secondly, although text can be printed in different fonts, words are consistent in their representation in the lexicon (i.e., they are abstract and independent of their visual characteristics). Therefore, information about words is well integrated across eye movements, regardless of whether the letters change between upper case and lower case or whether the case stays the same (McConkie & Zola, 1979; Rayner, McConkie & Zola, 1980). Objects, on the other hand, can be represented in any number of ways (e.g., with different viewing perspectives) and there is more inconsistency with respect to the correspondence between visual input and mental representation.

Eye movements during speech production are sensitive to many properties of the to-be-named object. In particular, the difficulty with which an object can be identified increases the amount of time the speaker must look at it. Difficulty identifying the object could be visually or linguistically based. For example, Meyer, Sleiderink and Levelt (1998) demonstrated that mean viewing time is modulated by visual stimulus properties such as whether the contours of the line drawings that represent the to-be-named objects were intact or partially deleted. Furthermore, some objects that are visually similar (e.g., a cow and a horse) may require more fixations and longer viewing times, targeted to a part of the object that distinguishes it from visually similar ones (e.g., the head of an animal or the bristles on a broom). Additionally, lexical characteristics of the object, which are properties of the abstract internal representation of the word, not the physical object, modify eye movement behavior. Research has demonstrated strong influences of lexical properties such as word frequency (Meyer et al., 1998), word length (number of syllables; Zelinsky & Murphy, 2000), codability (number of alternate names; Griffin, 2001), and phonological properties (phonological priming; Meyer & van der Meulen, 2000).

Meyer and Dobel (2003) reported that when Dutch speakers were asked to describe simple noun phrases such as "de bal en de vork"—"the ball and the fork"—speech onset latencies were equal to latencies when describing complex noun phrases such as "de kleine groene bal en de vork"—"the small green ball and the fork." However, viewing times on the first object were much longer in the complex noun phrase condition (i.e., when asked to describe more details about the first object) than in the simple noun phrase condition. These data show that the amount of time it takes to start speaking does not reflect the amount of time it takes to encode the entire intended utterance. It seems that speakers start to speak as soon as they have something to say regardless of how much they are going to say about that object (Bock, 1982). On the other hand, the amount of time spent looking at an object reflects the amount of time needed to encode and plan the entire utterance referring to it. These data illustrate how useful eye movement measures are in studying speech production when speech onset latencies are uninformative.

Parallel vs. Serial Processing in Multiple Object Naming

A longstanding topic of interest to researchers in many fields of cognitive psychology is the extent to which we are able to process more than one item at one time. This is a popular topic with respect to language comprehension and visual search, as well as the incrementality of speech production. There is no doubt that, in terms of speech output, language production must be incremental. Because of limitations of the oral-muscular system, we are only capable of articulating one word at a time. Even though this characteristic of speech imposes seriality at a certain level of processing, other levels of representation or processing may still allow parallelism and it is the task of the researcher to look beyond the serial nature of the behavior to discover the serial or parallel nature of the underlying cognitive processes.

To study the parallel nature of speech production, researchers have turned to the multiple object-naming paradigm in which the subject's task is to name two or more objects in succession. In gaze-contingent display-change experiments of multiple object naming, on some trials the second object changes during the saccade toward it (Meyer & Dobel, 2003; see also Pollatsek, Rayner, & Collins, 1984). In the display change trials, half of the time the object changes to an unrelated object and half of the time it changes to a different visual token of the same object (e.g., two different pictures of a book). Meyer and Dobel found that viewing times were longest when the target object had changed from an unrelated object, fastest when the target had not changed, and intermediate (significantly different from both the identical and unrelated conditions) when the target had changed from a conceptually identical but visually dissimilar object. They reported that there was no such facilitation for semantically related items (e.g., lion and tiger) or phonologically related items (e.g., cat and cap).

Although Meyer and Dobel (2003) reported no phonological facilitation for words that share the first phonemes, Morgan and Meyer (2005) reported a phonological preview benefit when the preview and the target were homophones and so shared 100% of their phonology (see also Pollatsek et al., 1984).

Morgan, van Elswijk, and Meyer (2008) conducted a word probe experiment in which two line drawings of objects were shown on the screen and the subject's task was to name both of the objects, starting with the left one. On half the trials one of the images was replaced with a word probe and the rest of the display was masked. The probe and mask appeared either 150 ms or 350 ms after the subject fixated the first object or 150 ms after fixating the second object. Word probes were either phonologically related (shared the first syllable) or unrelated (shared no phonemes) with the target. Morgan et al. found that the phonologically related probes showed facilitation relative to the unrelated primes only at the 350 ms SOA when it was in the first object location. When the probe appeared in the second location, facilitation was found at the 150 ms SOA. Morgan et al. argued that these data suggest that phonological information was obtained from the second object extrafoveally, while the subject was still processing the foveal object. The difference between the facilitation for word probes which share the first phoneme in the Morgan et al. (2008) experiment and the lack of facilitation from objects which share first phonemes reported by Meyer and Dobel (2003) is most likely due to the fact that word probes access phonology faster than pictures.

There is evidence that processing resources for object naming may be limited and distributed over multiple objects. Therefore, the extent to which one object is more difficult to name decreases the amount of processing that can be done on another object. For example, Meyer, Ouellet, and Hacker (2008) found that the homophone preview benefit demonstrated by Morgan and Meyer (2005) can be modulated by the difficulty of the foveal object. Overall, gaze durations on the second object were slower when the first object was difficult to name, and the magnitude of the preview benefit was smaller. Malpass and Meyer (2010) reported an extrafoveal-on-foveal effect in object naming: the difficulty of naming the second object affected how long subjects looked at the first object. If the second object was easy, subjects looked longer at the first object than if the second object was difficult. Furthermore, this effect went away when the first object was presented upside-down, indicating that foveal difficulty modulated the extrafoveal-on-foveal effect.

There are consistently reported effects of extrafoveal preview benefit of the directly following object in object naming tasks (Meyer et al. 2008; Morgan & Meyer, 2005). Therefore there must be at least some parallel processing of the foveal and next-to-be-named extrafoveal object. These effects are seen with both phonological (homophonous; Meyer et al. 2008; Morgan & Meyer, 2005) and semantically related extrafoveal previews (Meyer & Dobel, 2003). Given these findings, it seems that there is some processing of linguistic-level representations of the extrafoveal object; parallel extrafoveal processing is not restricted to visual processing. Thus far, however, the reported studies have only investigated extrafoveal preprocessing of the immediately subsequent object.

Recently, studies by Schotter, Ferreira, and Rayner (2009) investigated the timing of parallel processing of the foveal and next-to-be-named extrafoveal object, the extent of parallel processing (i.e., whether there is preview benefit from the third-to-be-named object), and whether parallel processing is restricted to items in the task. In one experiment, Schotter et al. presented triplets of objects oriented in an inverted equilateral triangle. The subject's task was to name the objects in the order: top left, top right, bottom. While the subject was fixating the first object, the second object was a grey box, which was replaced by a preview object for 200 ms at different SOAs (50ms, 250ms, and 450ms) and then returned to the grey box. Once a saccade was made to that object, it changed to the target, and remained the target for the remainder of the trial. The preview object was either a mirror image of the target or an unrelated object. Schotter et al. found a preview benefit at all SOAs. They took these data to support the notion that the objects were processed in parallel because a serial attention shift account would predict that the relatedness effect would only be present at the late SOAs.

In a different experiment, Schotter et al. (2009) implemented a display change on the *third* object when the subject made a saccade between the first and second object, and measured gaze durations on the second object. The third object either changed from a mirror image of the target or an unrelated object. Schotter et al. found a preview benefit on the second object when the third object had changed during the saccade, indicating that while fixating the first object, subjects had processed information about the third object.

Schotter, Ferreira, and Rayner (2010) investigated whether objects that never need to be named will be processed in parallel with task-relevant objects. In this experiment, the visual display consisted of four objects, but only three of the objects (always in the same location) were ever named. The second location and the unnamed location were equidistant from the first object, and started the trial as grey boxes. During fixation on the first object, both the second object and the unnamed object changed to a preview object for 200ms and then reverted to the grey box. During the saccade from the first object to the second, the second object changed to the target, named object. The preview object in each location could either be related (a mirror image) or unrelated to the target that was ultimately in the second object location, manipulated in a 2×2 design.

Schotter et al. found a significant relatedness effect of the preview in the named (second object) location, but no effect of the relatedness of the preview in the unnamed location and no interaction. Essentially, a preview provided a benefit when the target was in the same location, but a related preview in an equidistant but unnamed location provided no additional preview benefit compared to an unrelated preview. These data indicate two possibilities: (1) either attention can be actively modulated to accommodate only task-relevant objects, or (2) all objects are processed, but the information obtained from one location is tied to that location and cannot be used to affect processing of an object in a different location.

To test these two possibilities, Schotter et al. conducted a second experiment, similar to the first, but instead of appearing in the unnamed location, the second preview appeared in the third-to-be-named location. They found an interaction such that subjects were only slower to process the target when both the previews were unrelated. They argued that these data suggest that information (1) is obtained from several objects in parallel, (2) is only obtained if that object is intended to be named, and (3) is not confined to its spatial location and can be used to benefit processing of objects in other locations. Indeed, these data are consistent with prior research showing that object priming is independent of spatial location (Henderson & Siefert, 2001; Pollatsek, Rayner & Henderson, 1990).

A Brief Comment on Seriality and Parallelism in Silent Reading and Multiple Object Naming

Whether lexical access in silent reading is serial or parallel is hotly debated and has been for about a decade (for a review, see Reichle, Liversedge, Pollatsek & Rayner, 2009). A fair amount of data suggests that lexical access is serial (Rayner, Juhasz, & Brown, 2007; Angele, Slattery, Yang, Kliegl, & Rayner, 2009). While some data suggest there is parallel lexical processing of words, these effects seem to occur only in highly constrained situations such as those that approximate, but are not reading (Kennedy, 1998, 2000; Kennedy, Pynte & Ducrot, 2002; Murray & Rowan, 1998) or during silent reading when the foveal word is very short and the effect sizes are quite small (Kliegl, Risse, & Laubrock, 2007; Radach, Glover, & Vorstius, 2007; Risse & Kliegl, 2009). On the other hand, the evidence for parallel processing in multiple object naming is more evident, as demonstrated by the preceding review. Why would reading be serial while object naming is parallel?

There are several differences between the two tasks that would cause reading to be serial while multiple object naming is parallel. Not only do the words need to be identified, but they also need to be integrated into the syntactic frame of the sentence and holistic conceptual framework. Multiple object naming, on the other hand, does not require that the objects be integrated in any way (neither spatially nor conceptually).

Additionally, the set of objects to be named is generally constrained in multiple object naming tasks. That is, the objects are shown to the subject beforehand so that the experimenter knows what word the subject will use to name it and can correct the subject if he or she uses a different word than is required. Additionally, the objects are repeated, often in the different conditions, for reasons preferred or required by the experimental design (e.g., to increase power). For this reason, the objects are more predictable, and as has been shown in reading, more predictable words (or in this case, objects) show larger preview benefits (Balota, Pollatsek & Rayner, 1985).

Furthermore, visual objects are generally more visually distinctive than words. Words are more difficult to identify in the parafovea because they are more visually confusable. For example, the words *cow* and *can* are more difficult to tell apart than the visual representations of a cow and a can. Similarly, in Chinese, where orthography and semantics are more closely tied than in alphabetic languages, there is evidence for a semantic preview benefit (Yan, Richter, Shu & Kliegl, 2009; Yang, Wang, Tong & Rayner, 2011), for which there is no evidence in alphabetic languages (Altarriba, Kambe, Pollatsek & Rayner, 2001; Hyönä & Haikio, 2005; Rayner, Balota & Pollatsek, 1985; White, Bertram & Hyönä 2008; but see Hohenstein, Laubrock & Kliegl, 2010). Therefore, in a situation in which visual information creates a tighter link to semantic information, visual processing may act as a route through which semantic information can be processed in parallel. In alphabetic orthographies this may not be possible, as the visual-to-semantic connection is mediated by phonological representations.

Lastly, seriality and parallelism have different advantages and disadvantages. One of the trade-offs between them is the ability to process a set of items more quickly (i.e., parallelism) vs. the ability to keep items separate and in order (i.e., seriality). It may be easier to process items in parallel when the starting representation contains the relationships between the items, as in production. In reading, on the other hand, the reader is naive to the ultimate relationship between the words, so it might be easier for the processing system to rely on the order in which the words are printed by processing them serially. Indeed, relying on the order of the words in reading can sometimes cause problems; the clearest evidence for this comes from the reading of garden path sentences (Frazier & Rayner, 1982), which cause readers to return to previously read text when the first interpretation they had constructed is wrong.

Conclusion

The issue of serialism and parallelism is a central debate in research on silent reading. Similar methodology has only recently been used to study the issue with regard to speech production. The aforementioned studies all tend to show evidence for parallel processing of multiple objects through preview benefits for phonologically and semantically related objects. There is also evidence for foveal load modulating the preview benefit and extrafoveal-on-foveal effects. Essentially, attention is distributed over multiple objects when speaking about them. The difference between seriality in silent reading and parallelism in multiple object naming is ascribed to several facts. There are more cognitive load demands (due to integrative processes) in silent reading, objects are more predictable in the multiple object naming task, and there is a tighter link between visual and semantic information in objects than in words. Lastly, it is less important to confine processing to the order of items when the relationship between those items is known at the start point than when the relationship must be constructed as the items are being processed.

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