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BRIEF REPORTS

Parallel Processing of Objects in a Naming Task

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The authors investigated whether speakers who named several objects processed them sequentially or in parallel. Speakers named object triplets, arranged in a triangle, in the order left, right, and bottom object. The left object was easy or difficult to identify and name. During the saccade from the left to the right object, the right object shown at trial onset (the interloper) was replaced by a new object (the target), which the speakers named. Interloper and target were identical or unrelated objects, or they were conceptually unrelated objects with the same name (e.g., *bat* [animal] and [baseball] *bat*). The mean duration of the gazes to the target was shorter when interloper and target were identical or had the same name than when they were unrelated. The facilitatory effects of identical and homophonous interlopers were significantly larger when the left object was easy to process than when it was difficult to process. This interaction demonstrates that the speakers processed the left and right objects in parallel.

Keywords: picture naming, eye movements, visual attention, homophones, priming

When speakers describe what they see, they must coordinate the visual and conceptual analysis of the event, scene, or picture with their speech planning processes and with the articulation of the utterance. One way of studying how they accomplish this is to record their eye movements along with their speech (e.g., Griffin & Bock, 2000; Meyer, Sleiderink, & Levelt, 1998). Researchers using this strategy have found that, in descriptive tasks, the speakers' eye gaze and speech are tightly synchronized: Speakers usually look at all objects they name, in the order of mention and with their eyes running only slightly ahead of their speech. For instance, when speakers name two objects, they typically look at the first object for 500–700 ms, move their eyes to the second object, and begin to say the name of the first object about 150–300 ms later (for reviews, see Griffin, 2004; Meyer & Lethaus, 2004).

Eye-tracking studies have shown that the time speakers spend looking at each object (the gaze duration) depends not only on the time they need to identify the object (Meyer et al., 1998) but on the time they require to select a suitable name from the mental lexicon (Belke & Meyer, 2007; Griffin, 2001; Griffin & Oppenheimer, 2006) and to retrieve the corresponding phonological form. For instance, Meyer and van der Meulen (2000) and Mortensen, Meyer, and Humphreys (in press) showed that phonological priming reduced not only the latencies to name objects but also the durations of the gazes to the objects. Several studies have found that speakers looked longer at objects with long names than at objects with shorter names (Meyer, Belke, Häcker, & Mortensen, 2007; Meyer, Roelofs, & Levelt, 2003; Zelinsky & Murphy, 2000; see also Korvorst, Roelofs, & Levelt, 2006; Roelofs, 2007).

These findings are important for theories of speech planning, because there is a tight coupling between saccadic eye movements and visual attention. Each saccade is preceded by a shift of the focus of visual attention to the new location (Deubel & Schneider, 1996; Hoffman & Subramaniam, 1995). The attention shift occurs at about the same time as the saccade programming begins and involves related neural circuits (e.g., Awh, Armstrong, & Moore, 2006; Eimer, van Velzen, Gherri, & Press, 2007; Moore, Amstrong, & Fallah, 2003). Assuming that the time needed to program a saccade is fairly constant, the sensitivity of the speaker's eye movements to conceptual, semantic, and phonological variables shows that the timing of the preceding attention shifts depends on these variables as well. The results of the eye-tracking studies therefore imply that the shift of the focus of visual attention from one object to the next occurs after the speaker has planned the name of the current object to the level of the phonological form. The timing of this shift suggests that descriptive utterances are planned in a highly sequential fashion, with little temporal overlap in the visual–conceptual or linguistic planning processes for successive objects and their names (Levelt & Meyer, 2000).

However, the focused object need not be the only object a speaker is processing. The area a person is attending to can include several objects, which may be processed with differing priorities (Cave & Bichot, 1999; Downing & Pinker, 1985; Goldsmith & Yeari, 2003; LaBerge & Brown, 1989). Thus, while a speaker's

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visual attention is focused on one object, other objects might be included in the attended area and might be processed simultaneously, with lower priority. Interobject saccades might therefore indicate shifts in the focus of visual attention and in processing priorities rather than signal when the processing of objects begins and ends.

Evidence that is consistent with this hypothesis comes from a study by Morgan and Meyer (2005; see also Morgan, van Elswijk, & Meyer, in press; Pollatsek, Rayner, & Collins, 1984). They asked speakers to name triplets of objects, arranged as in Figure 1, in the order left, right, and bottom object. As expected, the speakers usually looked at the objects in the order of mention. During a speaker's saccade from the left to the right object, the right object shown at trial onset (the interloper) was replaced by a new object (the target). This was the object the speaker should name. Interloper and target were identical objects, conceptually unrelated objects with homophonous names (e.g., *bat* [animal] and [baseball] *bat*), or unrelated objects. Morgan and Meyer found that the mean gaze duration for the targets was significantly shorter when target and interloper were identical or had the same name than when they were unrelated. This finding suggests that the speakers processed the interloper in parallel with the left object and that the processing of the target was facilitated when it was identical to the interloper or had the same name.

However, Morgan and Meyer's (2005) results are open to an alternative interpretation. Given that saccades are preceded by shifts of visual attention, it is possible that the speakers first attended exclusively to the left object and then—shortly before the overt eye movement—moved the focus of their visual attention and exclusively processed the right object. The interloper effects could arise when their gaze was still directed at the left object but their visual attention was already focused on the right object. According to this account, the speakers processed the objects sequentially but the processing of the right object began prior to fixation.

Our goal in the present experiment was to decide between these hypotheses. The experiment was similar to Morgan and Meyer's (2005) experiment, but we varied the ease of processing the left object in addition to the relationship between interloper and target.

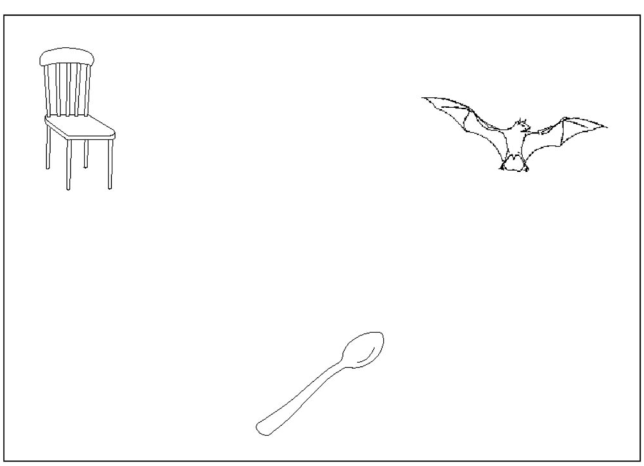

Figure 1. Arrangement of objects in Morgan and Meyer (2005; Experiment 2) and in the present study.

In one condition, the left objects were easy to identify and name; in the other condition, they were more difficult to process. If the left object and the interloper are processed in parallel and compete for processing resources, an interaction should arise: The interlopers should be processed less efficiently and their effects on the target gaze durations should be weaker if the left objects are difficult to process than if they are easy to process. By contrast, if the interloper begins to be processed only after the processing of the left object has been completed, the effects of the interlopers on the target gaze durations should be independent of the difficulty of processing the left objects.

Method

Participants

The experiment was conducted with 24 undergraduate students of the University of Birmingham. They were native speakers of British English and reported normal or corrected-to-normal vision.

Materials and Design

On each trial, the participants named three objects, arranged as in Figure 1, in the order left, right, and bottom object. During the saccade from the left to the right object, the right object shown at trial onset (the interloper) was replaced by a new object (the target), which the participant named.

To create the displays, we selected 108 drawings from a gallery provided by the Max Planck Institute for Psycholinguistics, Nijmegen, the Netherlands (see Appendix for a listing of the materials). For the left position, 24 easy and 24 difficult objects were chosen on the basis of a pretest, in which 12 participants had named 120 line drawings. The mean pretest naming latencies for the selected easy and difficult sets were 650 ms (*SE* = 22 ms, 0.3% errors) and 861 ms (*SE* = 29 ms, 2.3% errors), respectively, $t_1(11) = 9.96$; $t_2(46) = 11.26$, both $ps < .001$. In a second pretest, 12 participants carried out a word–picture matching task. On each trial, they saw a word followed by a picture and upon presentation of the picture decided whether or not the preceding word was its name. To avoid priming from the word to the picture, we presented the 48 experimental pictures on mismatching trials and presented another 48 pictures on matching trials. The mean decision latencies were 580 ms (*SE* = 26 ms, 3.41% errors) for the easy experimental pictures and 625 ms (*SE* = 31 ms, 2.78% errors) for the difficult experimental pictures, $t_1(12) = 4.38$, $p < .01$; $t_2(46) = 2.20$, $p < .05$ for the latency difference. This latency difference demonstrates that the pictures in the difficult set were more difficult to recognize than were those in the easy set. However, the sets also differed significantly in the mean age of acquisition of the object names, which was 31 months (*SE* = 2.6 months) for the easy set and 61 months (*SE* = 6.5 months) for the difficult set, according to the Morrison, Chappell, and Ellis (1997) norms, $t(44) = 4.38$, $p < .001$; no norms were available for two items. According to the COBUILD database (COBUILD Corpus of English Sentences, 2000), the items differed significantly in the mean frequency of the object names, which was 109 occurrences/million words (*SE* = 24) for the easy set and 23 occurrences/million words (*SE* = 7) for the difficult set, $t(46) = 3.49$, $p < .05$. Given these differences, the easy objects could probably be identified faster than could the difficult ones, and their names could be retrieved faster as well (e.g., Brysbaert & Ghyselinck, 2006; Jescheniak & Levelt, 1994; Juhasz, 2005). For the present purposes, this confound is not critical, because the goal was merely to create two picture sets that would differ strongly in processing difficulty.

For the right position, we selected 12 pairs of objects with homophonous names, which had also been used by Morgan and Meyer (2005). Each picture served as a target and as an interloper. In the identical condition, the same picture was used as target and interloper. In the homophone condition, the homophonous items were presented together (e.g., *bat* [animal] and [baseball] *bat*). In the unrelated condition, the pictures were recombined into semantically and phonologically unrelated pairs (e.g., *chest* [of drawers] and [baseball] *bat*).

Each participant saw each interloper–target pair once in combination with an easy left object and once in combination with a difficult left object. Each target was combined with a different left object in each of the three interloper conditions. Each left object was used once in each interloper condition.

Finally, 24 pictures were selected for the bottom position. Each of them was shown three times in the easy and three times in the difficult left object condition, each time in combination with a different target. Twenty-two further pictures were used on practice trials.

The objects were shown as black line drawings on a light gray background. They fit into frames of 6 cm × 6 cm (5.7° of visual angle for the participant). The distance between the pictures (center to center) was 15 cm (14.6°).

The experiment consisted of six test blocks. In each of them, each target was tested once, and eight targets were combined with identical, homophonous, and unrelated interlopers. In three successive blocks, all left objects were easy, and in the remaining blocks they were difficult. Twelve participants began with the easy and 12 with the difficult left objects. The order of the three easy blocks and of the three difficult blocks was counterbalanced across participants. The order of the trials within blocks was random and was different for each participant.

The first experimental block was preceded by six practice trials. Interloper and target were unrelated on four trials and identical on two trials.

Apparatus

We used the experimental package NESU (Max Planck Institute for Psycholinguistics, Nijmegen, the Netherlands) and an SMI EyeLink I eye-tracking system (SensoMotoric Instruments, Teltow/Berlin, Germany), which estimates the point of gaze of both eyes every 4 ms with a spatial accuracy of about 0.1°. The stimuli were presented on a 19-in. Samtron 95P Plus color monitor. The participants' speech was recorded using a Sony microphone and a Sony digital audiotape recorder.

Procedure

The participants were tested individually. At the beginning of the session, the participants saw a booklet showing all pictures and their names. We asked the participants to familiarize themselves with the materials and to use only the names given in the booklet to refer to the objects. They were to name the objects using a triplet of bare nouns, such as "banana, glasses, arm."

Then the headband of the eye tracker was placed on the participant's head and the system was calibrated. At the beginning of each trial, a fixation mark was presented in the top-left quadrant of the computer screen for 800 ms. Then the left object, interloper, and bottom object were displayed. The left and bottom object remained in view for 4 s, but the interloper was replaced by the target during the participant's saccade from the left to the right object. The intertrial interval was 2,500 ms. The experimental session took approximately 35 min to complete.

Results

The data obtained from 3 participants were discarded because more than 30% of the data was lost due to technical problems and naming errors. The results obtained from the remaining 21 participants are summarized in Table 1. Naming errors occurred on 5.49% of the trials. Analyses of variance yielded no significant main effect of left object difficulty or interloper type and no interaction.

Error trials were excluded from further analysis. The analysis of the participants' eye movements showed that the participants normally inspected the three objects in the order of mention. How-

Table 1
Rates of Naming Errors, Utterance Onset Latencies, and Gaze Durations for Left and Right Objects

Condition	Naming errors	Utterance onset latencies[a]	Gaze durations: Left object	Gaze durations: Right object
Easy left objects				
Identical interlopers	3.37	917 (29)	644 (41)	555 (30)
Homophonous interlopers	4.77	948 (31)	657 (42)	602 (25)
Unrelated interlopers	5.56	959 (34)	652 (39)	671 (29)
Difficult left objects				
Identical interlopers	5.36	987 (29)	709 (40)	609 (31)
Homophonous interlopers	6.35	1,032 (30)	735 (41)	633 (33)
Unrelated interlopers	7.54	1,012 (30)	714 (41)	675 (29)

Note. Errors are in percentages; other values are means (*SE*s) by participants, in milliseconds.
[a] The utterance onset was the onset of the name of the left object.

ever, on 18 trials (0.6% of the trials) they failed to look at the right or bottom object, and on 138 trials (4.57% of the trials) they did not look at the objects in the expected order. These trials were excluded from the further analyses.

The display change was initiated as soon as a saccade crossing the vertical midline of the screen was detected, and it was completed within 16 ms. The eye movement from the midline to the landing position on the right side of the screen took on average 24 ms. On all but three trials, which were eliminated from the analyses, the target was in place when the eyes landed on the right side of the screen. For the remaining trials, we computed the gaze durations for the left and right object as the time between the onset of the first fixation on the object and the offset of the last fixation before the shift of gaze to the next object.

The analysis of the utterance onset latencies (which correspond to the latencies to name the left object) showed that the participants began to speak significantly earlier (by 69 ms) when the left object was easy than when it was difficult, $F_1(1, 20) = 39.91$; $F_2(1, 23) = 44.24$, both *p*s $< .001$. In addition, there was a significant main effect of interloper type, $F_1(2, 40) = 9.46$, $p < .01$; $F_2(2, 46) = 4.02$, $p < .05$. The mean utterance onset latency was shorter when the interloper and target were identical (952 ms) than when they had homophonous names (990 ms) or were unrelated (986 ms). The interaction of left object difficulty and interloper type was not significant.

The analysis of the durations of the gazes to the left objects showed that the participants looked significantly longer, by 68 ms, at difficult than at easy left objects, $F_1(1, 20) = 66.67$; F_2 $(1, 23) = 45.13$, both *p*s $< .001$. The effect of interloper type and the interaction of left object difficulty and interloper type were not significant.[1]

For the durations of the gazes to the right objects, we obtained a significant main effect of interloper type, $F_1(2, 40) = 29.14$; $F_2(2, 46) = 40.25$, both *p*s $< .001$, with gazes being longest when interloper and target were unrelated objects (673 ms), intermediate when they had homophonous names (618 ms), and shortest when they were identical (583 ms). There was also a main effect of left object difficulty, with gazes being longer, by 29 ms, when the left object was difficult than when it was easy, $F_1(1, 20) = 10.26$; $F_2(1, 23) = 15.98$, both *p*s $< .001$. Most important, the effects of interloper type and left object difficulty interacted with each other, $F_1(2, 40) = 3.38$; $F_2(2, 46) = 4.25$, both *p*s $< .05$. The interaction arose because the size of the interloper effects was much reduced, by approximately 40%, in the difficult relative to the easy left object condition: The preview benefit from identical relative to unrelated interlopers decreased from 115 ms to 66 ms, and the preview benefit from homophonous interlopers decreased from 69 ms to 42 ms.

Analyses of simple effects showed that the effect of interloper type was significant when the left object was easy, $F_1(2, 40) = 30.47$; $F_2(2, 46) = 40.13$, both *p*s $< .001$, and when the left object was difficult, $F_1(2, 40) = 8.98$; $F_2(2, 46) = 9.23$, both *p*s $< .001$. Planned comparisons showed that the preview benefit from identical and from homophonous interlopers was significant ($p < .05$) in the difficult as well as in the easy left object condition. Thus, there were significant preview effects in the difficult left object condition, but they were weaker than were the preview effects in the easy left object condition.

Discussion

Our goal in the experiment was to determine whether the ease of processing the left object would affect how efficiently the participants could process the right object prior to fixation. It was therefore important for us to establish that the chosen sets of easy and difficult left objects indeed differed in processing difficulty. The significant differences in the average naming latencies and gaze durations between the two sets confirmed that this was the case. As explained above, the easy and difficult objects differed in the ease of object recognition but probably also in the ease of lexical selection and word form retrieval. Therefore, the observed differences in gaze durations and naming latencies could originate at the visual–conceptual level and/or the lexical level.

The duration of the gazes to the left objects was independent of the relationship between the interloper and target shown on the right side of the screen. This result is not surprising, given that the display change from interloper to target occurred only after the end of the gaze to the left object. By contrast, the utterance onset latencies were longer in the unrelated and homophone condition than in the identical condition. The participants typically began to speak after they had completed the eye movement to the right object. The effect of interloper type on the speech onset latencies probably arose because noticing the display change in the unrelated and homophone condition interfered with speech planning or self-monitoring processes that occurred after the shift of gaze to the right object.

As in Morgan and Meyer's (2005) study, the mean gaze duration for the right object was significantly shorter when interloper and target were identical or had the same name than when they were unrelated. This result demonstrates not only that the right object was recognized prior to fixation but that its name was activated as well (see also Meyer, Belke, Telling, & Humphreys, 2007; Morgan et al., in press). The most important finding is that the facilitatory effects of the identical and homophonous interlopers, though still significant, were much smaller in the difficult than in the easy left object condition. As explained above, preview effects could arise in two ways: The speakers could process the left object and the interloper in parallel, or the speakers could process them in sequence, with the processing of the interloper beginning as soon as the focus of visual attention shifted from the left to the right side of the screen. The observed interaction of left object difficulty and interloper type supports the parallel processing hypothesis: When the left objects were difficult, less capacity was available to the interlopers, which were processed less efficiently and therefore had weaker effects on the processing of the targets than when the left objects were easier to process.

The most straightforward version of the serial hypothesis does not predict the interaction: If speakers first attended exclusively to the left object and then, after its processing had been completed,

[1] One might also consider measuring the naming latencies for the right objects from the onset of the gaze to the right object. However, the participants usually began to inspect the right object well before they initiated the name of the left object; the average eye–speech lag was 289 ms. Thus, the right object naming latencies depended not only on the time required to process the right object after fixation but also on the durations of the name of the left object and were therefore less informative than were the gaze durations.

initiated the shift of visual attention and programmed the eye movement to the interloper, the difficulty of the left object should not affect the processing of the interloper and moderate its effect on the target. However, this argument presupposes a tight link between shifts of visual attention and saccade programming. Against this, one might speculate that speakers might carry out more shifts of attention to the right object without moving their eyes from the left object, or that the interval between the shift of attention to the right object and the completion of the corresponding eye movement might be longer when the left object is easy than when it is difficult. These proposals should be investigated in future research. At present, there is no evidence suggesting that the participants carried out any covert shifts of attention without moving their eyes, or that the timing of the shift of attention relative to the eye movement depended on the difficulty of the left object. As noted above, the available evidence suggests that saccade programming and the shift of attention to a new location begin at the same time (e.g., Awh et al., 2006; Castet, Jeanjean, Montagnini, Laugier, & Masson, 2006; Moore et al., 2003), and we are not aware of any findings suggesting that the time required to program or execute the saccade from the left to the right object should depend on the difficulty of the left object.[2] In short, in our view, the parallel hypothesis offers a more plausible and parsimonious account of our findings than does the serial hypothesis.

Several reaction time studies have shown that speakers producing phrases such as "cat and chair" often select both nouns before speech onset (e.g., Friedman, Martin, & Biegler, 2004; Meyer, 1996). However, these studies did not reveal whether the speakers processed the two objects in parallel or processed them sequentially but began to speak only when both nouns were available. The current results show that speakers can process two objects and can retrieve their names in parallel, though they obviously do not imply that speakers must engage in parallel processing whenever they name several objects.

Our results fit in well with models of speech planning that assume that speakers plan different parts of their utterances in parallel but with differing priorities. For instance, in the model proposed by Dell, Burger, and Svec (1997; see also Dell, 1986), a speaker who intends to name several objects in a particular order generates a plan representing this intention and creates an appropriate syntactic frame. The plan activates the conceptual units corresponding to the objects and the associated linguistic representations. Initially, the units corresponding to the object to be named first are activated most strongly, but the units corresponding to the second object also receive some activation. When the units corresponding to the first object have been selected, their activation levels decay and the units corresponding to the second object become most strongly activated. Our results suggest that this type of model finds a counterpart in the way speakers allocate visual attention to the objects they name.

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Appendix

Materials

Easy left object: banana, bed, bell, book, butterfly, chair, dog, door, ear, elephant, eye, fish, foot, hand, heart, ladder, lamp, leaf, pencil, scissors, shoe, star, sum, umbrella.

Difficult left objects: boot, chisel, cigar, cigarette, dress, hair, hammer, lemon, lion, lobster, onion, plug, potato, ruler, skirt, stool, thumb, toaster, tomato, toothbrush, tree, vase, vest, violin.

Right objects: bat, bow, boy/buoy, chest, glasses, horn, mouse, nail, nut, pipe, spade, table.

Bottom objects: arm, barrel, bowl, camel, cat, chain, clock, comb, drum, frog, hat, key, monkey, mushroom, nose, owl, pig, rabbit, saw, snake, spoon, watch, wheel, whistle.

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