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Phonological priming effects on speech onset latencies and viewing times in object naming

ANTJE S. MEYER and FEMKE F. VAN DER MEULEN
Max Planck Institute for Psycholinguistics, Nijmegen, The Netherlands

An earlier experiment (Meyer, Sleiderink, & Levelt, 1998) had shown that speakers naming object pairs usually inspected the objects in the required order of mention (left object first) and that the viewing time for the left object depended on the word frequency of its name. In the present experiment, object pairs were presented simultaneously with auditory distractor words that could be phonologically related or unrelated to the name of the object to be named first. The speech onset latencies and the viewing times for that object were shorter after related distractors than after unrelated distractors. Since this phonological priming effect, like the word frequency effect, most likely arises during word-form retrieval, we conclude that the shift of gaze from the first to the second object is initiated after the word form of the first object's name has been accessed.

In studies of language production, speakers often name single objects in one-word utterances (e.g., *cross* or *ball*). On the basis of the results of such studies, detailed models of object naming have been proposed (e.g., Glaser, 1992; Humphreys, Lamote, & Lloyd-Jones, 1995; Humphreys, Riddoch, & Quinlan, 1988; Levelt, Roelofs, & Meyer, 1999). Though adult speakers sometimes produce one-word utterances, they often (perhaps more often) say sentences in which they refer to several concepts and express their relationships. In order to fluently produce such utterances, speakers must select the concepts to be mentioned and the corresponding words in close temporal succession. The issue addressed in the present paper is how the planning processes for the words of an utterance are coordinated with each other in time.

Before turning to the coordination of the planning processes, we will outline which processes take place when a speaker names a single object. Our working model of object naming (Levelt et al., 1999) distinguishes between the visual–conceptual processes involved in object recognition and the following lexical access processes. Visual–conceptual processing comprises two steps. First, a percept is computed from the visual image. A percept is an integrated representation of the visual properties of the object, such as its shape, size, color, and current orientation. Second, an appropriate lexical concept is accessed. Lexical concepts can be viewed as nodes in a semantic network. Labeled connections (e.g., "is-a," "has-a") express their relationships (Roelofs, 1992). Lexical concepts differ from other concepts in that they have links to entries in the mental lexicon. Lexical access also comprises two main steps. The first step is the selection of a syntactic word unit, a lemma. The second step is the retrieval of the corresponding word form. Word-form retrieval can further be broken down into the generation of a fairly abstract phonological representation and the subsequent generation of a more detailed context-specific phonetic representation, which defines the articulatory commands to be carried out.

When a speaker names two objects in one utterance (e.g., *the cross and the ball*), the conceptual and lexical processes must be carried out for each of the objects. Meyer, Sleiderink, and Levelt (1998) examined how the two sets of processes were coordinated with each other by monitoring when and for how long speakers looked at each object. On the basis of the results of earlier studies showing that people usually fixate on objects they wish to identify (for reviews, see Rayner, 1998, and Rayner & Pollatsek, 1992), they expected that speakers would fixate on each of the objects to be named. Furthermore, they assumed that the time spent fixating on an object would reflect on the time spent attending to it. This assumption was based on the results of a number of studies showing that eye movements are obligatorily preceded by corresponding shifts of visual attention. Thus, when an eye movement from one object to the next is observed, it can be concluded that visual attention has also shifted (Deubel & Schneider, 1996; Hoffman & Subramaniam, 1995; Irwin & Gordon, 1998; Kowler, Anderson, Dosher, & Blaser, 1995; Rayner & Pollatsek, 1992; Shepherd, Findlay, & Hockey, 1986). As expected, Meyer et al. (1998) found that, on most trials, the speakers first inspected the left object, which they had to name first, and then the right object. Importantly, the viewing time for the left object (i.e., the time interval between the onset of the first fixation on that object and the offset of the last fixation before the shift of gaze to the right object) depended on the frequency of its name: Speakers looked longer at objects with low-frequency names than at objects with high-

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frequency names. The naming latencies were also longer for objects with low-frequency names than for those with high-frequency names.

Other studies have also found that objects with low-frequency names were named more slowly than objects with high-frequency names (e.g., Oldfield & Wingfield, 1965; Wingfield, 1968). Jescheniak and Levelt (1994) have shown that a name-frequency effect on picture-naming latencies can be found even when the objects with high- and low-frequency names are matched for ease of recognition. In an experiment in which speakers produced homophones (e.g., *more* [noun/adverb] or *I/eye*), which have different lemmas but share the word form, they showed that the speech onset latencies depended on the frequencies of the word forms, not the lemmas. Thus, they argued that word-frequency effects in speech production arise during the retrieval of the phonological forms of words.

In a control experiment using an object/nonobject categorization task, Meyer et al. (1998) showed that their objects with high- and low-frequency names did not differ in the ease of recognition. In that experiment, neither speech onset latencies nor viewing times were systematically affected by the frequencies of the object names. Therefore, the frequency effects found in the object-naming experiment carried out by Meyer et al. most likely arose during lexical access. Following Jescheniak and Levelt (1994), the origin of these effects can be further narrowed down to the retrieval of the phonological forms of the words. Thus, it can be concluded that the speakers' decision to shift gaze from one object to the next was contingent on the retrieval of the first object's name.

This conclusion is interesting because lexical access to an object name is usually taken to be based on conceptual rather than visual information. After a lexical concept has been selected, visual information should no longer be necessary to retrieve the lemma and phonological form of the object name. In addition, lexical access is generally assumed to be a fairly automatic process, not requiring much conscious attention (e.g., Levelt, 1989, p. 28). Therefore, speakers should be able to shift gaze, and visual attention, from one object to the next as soon as the first object has been recognized and permit lexical access to the first object's name to run in parallel with the visual–conceptual processing of the second object. Yet, the speakers tested by Meyer et al. (1998) apparently adopted a more sequential processing strategy, fixating on the left object until most of its linguistic processing had been completed and only then turning to the right object.

Meyer et al.'s (1998) conclusion that the shift of gaze was contingent on word-form retrieval was based on the difference in viewing times for two separate sets of objects, which differed in name frequency but perhaps also in other respects. The object/nonobject categorization experiment showed that the high- and low-frequency objects were equally easy to distinguish from nonobjects. But, in order to carry out this task, a fairly global categorization of the pictures (e.g., as some kind of animal or vehicle) may suffice, whereas more thorough processing may be necessary to select a lexical concept (e.g., goat or cow) and lemma. It cannot be ruled out that the time required for these processes differed for the objects with high- and low-frequency names.

In the present experiment, we therefore used a within-items design and tested whether the mean viewing time for one set of objects could be reduced by facilitating access to the phonological forms of their names. Dutch participants named object pairs in noun phrases, such as *het kruis en de bal* (*the cross and the ball*). Each object pair was accompanied by an auditory distractor word, to which no overt reaction was required. The distractor was either related in phonological form to the name of the left object, which the speakers named first, or unrelated. We measured the utterance onset latencies and the viewing times for the left object. In earlier picture–word interference experiments, shorter speech onset latencies had been observed after phonologically related distractors than after unrelated distractors (Meyer, 1996; Meyer & Schriefers, 1991). This facilitatory phonological effect can be allocated at the level of word-form retrieval (Roelofs, 1997). When an unrelated distractor is presented, its phonological segments are activated and compete with those of the target name for selection. By contrast, some of the segments of a phonologically related distractor also occur in the target word form. Hence, these segments do not compete; instead, their selection as part of the target word form is facilitated due to the activation received during the processing of the distractor. Consequently, naming latencies are shorter in the phonologically related condition than in the unrelated condition. We expected to replicate this phonological priming effect on the speech onset latencies in the present study. The most important prediction concerned the viewing times for the left object: If speakers fixate on an object until the phonological form of its name has been retrieved, the mean viewing time should be shorter in the phonologically related condition than in the unrelated condition.

Each object pair was combined with two types of related distractors: The begin-related distractor shared word-initial segments with the name of the left object (as in *kruis–kruid* [*cross–herb*]), and the end-related distractor shared word-final segments (as in *kruis–sluis* [*cross–lock*]) with it. In addition, there were, of course, unrelated distractors. Our working model does not predict that begin- and end-related distractors should differ much in their effects, and, in some experiments, very similar results have been obtained for begin- and end-related stimulus pairs (Collins & Ellis, 1992; Meyer & Schriefers, 1991). However, many authors have argued for a special status of word onsets, on the basis, for instance, of the fact that they are much more often involved in speech errors than word-internal or word-final segments (e.g., Fromkin, 1971; Garrett, 1975; Shattuck-Hufnagel, 1987). In addition, different patterns of results have been obtained for word pairs sharing word-initial or word-final segments in repeated pronunciation experiments (e.g., O'Seaghdha & Marin, 2000; Sevald & Dell, 1994). In the present experiment, begin- and end-related distractors were tested in order to explore whether their effects on the viewing times for the left object would differ.

METHOD

Participants

The experiment was carried out with 28 undergraduate students of Nijmegen University. They were native speakers of Dutch and had normal or corrected-to-normal vision and normal hearing. Two participants' data were lost due to technical problems. Hence, the analyses are based on the results obtained from 26 participants.

Materials

Pictures. The experimental pictures were 34 line drawings, each showing two common objects next to each other (see the Appendix). The pictures were selected from a gallery available at the Max Planck Institute for Psycholinguistics. The names of all objects shown on the left side of the screen were monosyllabic and began and ended in a consonant or consonant cluster. The names of the objects shown on the right had one or two syllables. The names of the two objects shown together were unrelated in meaning and phonological form. In addition to the experimental picture pairs, there were six practice pairs.

The objects were presented as black line drawings on a gray background. They were scaled to fit into a rectangular frame of 8.1 × 7.45 cm, corresponding to visual angles of approximately 7° horizontally and 6.5° vertically when viewed from the participant's position. The distance between the midpoints of these imaginary frames was 15 cm (13°).

Distractors. For each experimental picture, two distractor words were selected that were phonologically related to the name of the left object (see the Appendix). The begin-related distractor shared the onset consonant or consonant cluster and the vowel or diphthong with object name. The end-related distractor shared the vowel or diphthong and the word-final consonant or consonant cluster with the object name. The mean word form frequencies for the two types of distractors according to the CELEX database were similar: 19.7 ($SD = 5.70$) and 32.2 ($SD = 7.4$) per million. The average length of the begin-related and end-related distractors was 530 msec ($SD = 100$ msec) and 530 msec ($SD = 117$ msec), respectively. The practice items were combined with phonologically unrelated distractor words.

Design

The experiment included four experimental conditions using the same pictures. In the begin-related and end-related conditions, the pictures were combined with the phonologically related distractors described above. In addition, there were two control conditions. In the begin-unrelated condition, the same distractors were used as in the begin-related condition. However, they were combined with different pictures such that the distractors and picture names were not related in meaning and that the overlap in phonological form was minimized. In the same fashion, in the end-unrelated condition, the end-related distractors were assigned to new pictures. Targets and unrelated distractors never shared the onset consonant or vowel. Fifty of the 68 pairs shared no segments at all; but 8 pairs in the begin-unrelated condition and 10 pairs in the end-unrelated condition shared one segment. The shared segment appeared either in the coda in both words (as in *spook–bek* [*ghost–beak*]) or in the onset in one word and in the coda in the other word (as in *sok–ras* [*sock–race*]).

The experiment included four test blocks, in each of which each picture was presented once. Thus, each block included 34 experimental trials. In each block, eight or nine pictures were combined with the same type of distractor. For instance, in the first block, eight pictures each were combined with begin-related and begin-unrelated distractors, and nine pictures each were combined with end-related and end-unrelated distractors. In each block, each picture was combined with a different distractor. For example, those pictures that were combined with begin-related distractors in the first block were combined with begin-unrelated distractors in the second block. Similarly, the pictures that were accompanied by begin-unrelated distractors in the first block were accompanied by end-related ones in the second block, and so on. The order of the four blocks was balanced across participants using a Latin square design. By the end of the experiment, each participant had seen each picture four times, once in combination with each distractor. The order of the items within blocks was random and different for each participant. At the beginning of the first block, all practice items were presented once. At the beginning of each of the following blocks, two randomly selected practice items were repeated.

Apparatus

The experiment was controlled by a Compaq 486 computer. The pictures were presented on a ViewSonic 17PS screen. The distractor words were spoken by a female speaker and recorded using a SONY DCT55 DAT recorder. They were digitized with a sampling frequency of 16 kHz and stored on the hard disk of the computer. They were presented using Sony MDR-E757 earphones. The participants' speech was recorded using a Sennheiser ME400 microphone and a SONY DTC55 DAT recorder. Speech onset latencies were measured using a voice key.

Eye movements were monitored using an SMI EyeLink-Hispeed 2D eye-tracking system. Throughout the experiment, the computer recorded the onset and offset times and spatial coordinates of the participants' fixations. The signal from the eye tracker was sampled every 4 msec. Both eyes were monitored, but only the data from the right eye were analyzed.

Procedure

The participants were tested individually. They were seated in a quiet room approximately 60 cm in front of a monitor. They first received a booklet including drawings of the practice and experimental objects with their names. They were told that they would see object pairs, which they should name, starting with the left object and using the definite determiners (*de* or *het* [*the*], depending on the grammatical gender of the noun) and the conjunction *en* (*and*). Thus, they were to produce utterances, such as *het kruis en de bal* (*the cross and the ball*). They were also informed that they would hear words, which they should try to ignore. When the participant had read the instruction and studied the picture names, the earphones were positioned, the headband of the eye-tracking system was mounted, and the system was calibrated. After successful calibration, the four test blocks were administered. There were pauses of about 1 min between blocks.

At the beginning of each test trial, a fixation point was presented in the center of the screen for 800 msec. Following a blank interval of 200 msec, an object pair was presented for 3,000 msec. After another blank interval of 500 msec, the next trial began. In the begin-related and begin-unrelated conditions, the auditory distractor word began at picture onset. End-related and end-unrelated distractors began slightly earlier. For each of these distractors, we determined the length of the word-initial consonant or consonant cluster, which was, on average, 114 msec ($SD = 9$ msec). The distractors were presented such that the consonant–vowel transition coincided with the picture onset. Thus, in the begin-related and end-related conditions, the first segment shared by distractor and target was presented at picture onset. Meyer and Schriefers (1991) showed that more robust priming effects are obtained under these conditions than when the word onset of the distractors is aligned with the picture onset.

RESULTS

The data from 324 trials (9.2%) were discarded because the speakers used incorrect object names (53 cases) or stuttered or repaired their utterance (102 cases), because the latency exceeded 1,800 msec (56 cases), or because the participants began the response with a nonspeech sound (e.g., *eh* . . . ; 113 cases). As Table 1 shows, the error rates in the four distractor conditions were very similar.

The mean speech onset latencies per distractor condition are also shown in Table 1. As expected, the mean latencies were shorter after phonologically related distractors than after unrelated distractors. This effect amounted to 35 msec and was highly significant [$F1(1,25) = 24.01$ (by participants); $F2(1,33) = 19.33$ (by items); both ps < .01]. The effect was slightly stronger when the shared segments appeared word-finally than when they appeared word-initially (42 vs. 29 msec), but the interaction of relatedness and position was not significant [$F1(1,25) < 1$; $F2(1,33) = 1.05$]. There was, however, a significant main effect of position [$F1(1,25) = 35.76$; $F2(1,33) = 17.56$; both ps < .01]. The mean latency across the begin-related and begin-unrelated conditions was longer by 31 msec than the mean across the end-related and end-unrelated conditions. This effect had not been anticipated. Since, in the begin-related and begin-unrelated conditions different distractor words were used than in the end-related and end-unrelated conditions, it was probably due to accidental properties of the two sets of distractor words. The reaction times were longer in the first test block (847 msec) than in the following blocks (825, 817, and 823 msec, respectively, for the second, third, and fourth blocks), but the main effect of test block was significant only by items [$F2(3,99) = 6.11$, $p < .01$] but not by participants [$F1(3,75) = 1.54$]. None of the interactions involving the variable test block was significant.

Table 1
Means and Standard Errors (by Participants) of Naming Latencies and Viewing Times (in Milliseconds) and Error Rates (%) After Begin-Related, Begin-Unrelated, End-Related, and End-Unrelated Distractors

	Dependent Variable				
	Naming Latency		Viewing Time		
Distractor Type	*M*	*SE*	*M*	*SE*	Error Rate
Begin-Related	828	27	505	16	9.05
Begin-Unrelated	857	23	559	17	10.41
End-Related	793	23	493	14	8.84
End-Unrelated	835	22	540	17	8.35

For the analysis of eye movements, graphical software was used that displayed, for each trial, the locations of the participants' fixations as dots superimposed on the line drawing shown on that trial and, in another window, the onset and offset times of the fixations. All fixations that lay inside the contours of an object or less than 1.5° away from an outer contour were scored as pertaining to that object.

As in the study by Meyer et al. (1998), the participants almost always (on 98.4% of the trials) first fixated on the left object and then turned to the right object. Occasionally, there was either no fixation on the left object (28 cases) or no fixation on the right object (16 cases), or the participants first fixated on the right and then on the left object (16 cases). These cases were excluded from the further analyses. On trials on which the participants inspected the left object first, the first fixation on the left object began, on average, 43 msec after picture onset. The mean number of fixations was 2.08, and the last fixation before the shift of gaze to the right object ended, on average, 569 msec after picture onset and 259 msec before speech onset. The first fixation on the right object began, on average, 649 msec after picture onset and 179 msec before speech onset. On 53.2% of the trials, the participants' gaze returned to the left object toward the end of the trial, with a mean latency of 1,749 msec after picture onset. Perhaps the participants looked at the left object again to check the correctness of the utterance or to prepare for the next trial. On 32% of the trials, the participants fixated on the right object until the end of the trial; on 14.8% of the trials, they returned to the middle of the screen, where they could expect the fixation point for the next trial.

The main goal of the experiment was to determine whether the time spent looking at the left object of a pair in preparation for the utterance depended on the type of distractor. The dependent variable quantifying the time spent looking at the left object of a pair was viewing time, defined as the time interval between the beginning of the first fixation on that object and the end of the last fixation before the shift of gaze to the right object.[1] The results obtained for the viewing times were very similar to those obtained for the speech onset latencies; the trial-by-trial correlation between the variables was $r = .53$, $p < .01$. The mean viewing time for the left object was significantly shorter when the distractor was related to the left object's name than when it was unrelated [$F1(1,25) = 38.63$; $F2(1,33) = 29.53$; both ps < .01]. The facilitatory effect was 54 msec for begin-related distractors and 47 msec for end-related ones (see Table 1). This small difference in the size of the priming effect was not significant (both Fs < 1). Viewing times, like naming latencies, were significantly shorter after end-related or end-unrelated distractors than after begin-related or begin-unrelated ones [$F1(1,25) = 13.40$, $p < .01$; $F2(1,33) = 5.48$, $p < .05$]. Neither the main effect of test block nor any interaction involving this variable approached significance.

DISCUSSION

In the present experiment, speakers produced noun phrases, such as *the cross and the ball*, while listening to distractor words that were phonologically related or unrelated to the name of the object mentioned first. As in earlier studies (e.g., Meyer, 1996; Meyer & Schriefers, 1991), the speech onset latencies were shorter after related distractors than after unrelated distractors. The strength of this phonological priming effect was independent of whether distractor and target shared word-initial or word-final segments. As noted above, the working model of object naming adopted here (Levelt et al., 1999) does not predict a difference in the effects of begin-related and end-related distractors.

The main point of the experiment was to examine whether the mean viewing time for the left object would be systematically affected by the type of distractor, and this turned out to be the case. When phonologically related distractors were presented, the mean viewing time for that object was significantly shorter than when unrelated distractors were presented. Again, the size of this facilitatory effect was independent of the location of the shared segments.

As noted in the introduction, a study by Meyer et al. (1998) had shown that objects with high-frequency names were named more rapidly and inspected for shorter periods of time than objects with low-frequency names. There are good reasons to allocate the effects of word frequency at the level of word-form retrieval. However, it is difficult to prove that this is the only locus of the effects, because objects differing in the frequencies of their names may always differ in other respects as well. The present experiment had a within-items design and demonstrated that, when the time necessary to retrieve the phonological forms of the object names was reduced by presenting form-related distractors, the mean viewing time for the objects was also reduced. Thus, the two studies provide converging evidence for the conclusion that the time speakers spend looking at an object they wish to name depends, among other things, on the time required to access the form of the object's name.

Our working model of object naming assumes that speakers first recognize the object, then select a lemma, and then access the corresponding word form. During word-form retrieval, speakers first generate an abstract phonological representation and then a more detailed phonetic representation. The facilitatory effect of phonologically related distractors can best be explained as arising during the selection of the words' segments—that is, during the generation of the phonological representation (Levelt et al., 1999; Roelofs, 1997). Thus, our experimental results show that the shift of gaze was initiated after the segments had been selected.

Had speakers also generated the phonetic representation of the first object name before turning to the second object? Most likely not. The last fixation on the left object ended, on average, 569 msec after picture onset, but the decision to initiate the eye movement must have been made at least 100 msec earlier—that is, 400–470 msec after picture onset. Estimates of the time course of lexical access based on the results of a large number of studies (Indefrey & Levelt, 2000) suggest that, by that time, an abstract phonological representation of the object name can be generated, but the phonetic encoding almost certainly still remains to be done.

Why did the speakers look at the objects for such long periods? Why didn't they look away as soon as they had identified the left object and retrieve the lemma and form of its name in parallel with the visual and conceptual processing of the right object? This serial processing strategy may be a way to minimize interference among conceptual and linguistic units pertaining to different objects. As long as one object is fixated on and attended to, its conceptual and linguistic units are strongly activated. As soon as the attention shifts to the next object, the units pertaining to that object become the most highly activated ones. If the shift is initiated too early, interference may arise between the units pertaining to the two objects, which may slow down the encoding processes or lead to errors.

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NOTE

1. The same pattern of results was obtained in analyses of gaze durations defined as the summed durations of the fixations on the left object excluding saccades.

APPENDIX
Names of the Experimental Objects and Distractors

bed–gieter, bek, wet (bed–watering can, beak, law)
been–tent, beet, steen (leg–tent, bite, stone)
berg–kleed, bel, merg (mountain–rug, bell, marrow)
boek–anker, boer, vloek (book–anchor, farmer, curse)
bom–fornuis, bok, som (bomb–oven, goat, sum)
boor–masker, boon, koor (drill–mask, bean, choir)
bot–wiel, bos, pot (bone–wheel, forest, pot)
bril–vuur, brik, spil (glasses–fire, brick, pivot)
glas–vliegtuig, glans, ras (glass–airplane, shine, race)
hek–brood, hel, gek (fence–bread, hell, madman)
hoed–pakje, hoek, moed (hat–parcel, corner, courage)
huis–blik, huig, luis (house–tin, uvula, louse)
jurk–spijker, juf, kurk (dress–nail, teacher, cork)
kast–bloem, kam, last (closet–flower, comb, burden)
kies–vlot, kiel, lies (tooth–raft, blouse, groin)
kroon–wekker, kroost, loon (crown–alarm clock, offspring, pay)
kruis–bal, kruid, sluis (cross–ball, herb, lock)
mes–bureau, mep, hes (knife–desk, slap, smock)
net–sleutel, nek, vet (net–key, neck, fat)
neus–riem, neut, keus (nose–belt, drop, choice)
pijp–kar, pijn, rijp (pipe–cart, pain, hoar-frost)
raam–ballon, raaf, naam (window–balloon, raven, name)
schip–puzzel, schil, lip (ship–puzzle, peel, lip)
snoer–clown, snoep, vloer (cord–clown, sweets, floor)
sok–fles, sop, lok (sock–bottle, suds, lock)
spook–blad, spoor, rook (ghost–leaf, trail, smoke)
tas–fluit, tang, pas (bag–flute, tongs, step)
teen–slot, teek, peen (toe–clasp, tick, parsnip)
trap–borstel, tram, klap (step–brush, tram, blow)
vaas–hart, vaat, gaas (vase–heart, wash up, gauze)
vest–pistool, vel, mest (waistcoat–pistol, skin, manure)
wolk–orgel, worm, dolk (cloud–organ, worm, dagger)
zak–lepel, zalf, dak (sack–spoon, ointment, roof)
zwaard–web, zwaan, staart (sword–web, swan, tail)

Note—The entries in each line are, in order, the names of the left and right objects and the begin-related and end-related distractors. English translations appear in parentheses.

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