

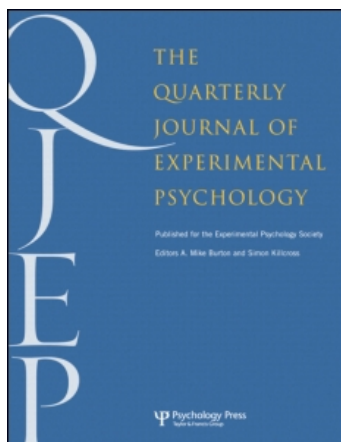
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## Refractory effects in picture naming as assessed in a semantic blocking paradigm

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In the cyclic semantic blocking paradigm participants repeatedly name sets of objects with semantically related names (*homogeneous sets*) or unrelated names (*heterogeneous sets*). The naming latencies are typically longer in related than in unrelated sets. In Experiment 1 we replicated this semantic blocking effect and demonstrated that the effect only arose after all objects of a set had been shown and named once. In Experiment 2, the objects of a set were presented simultaneously (instead of on successive trials). Evidence for semantic blocking was found in the naming latencies and in the gaze durations for the objects, which were longer in homogeneous than in heterogeneous sets. For the gaze-to-speech lag between the offset of gaze on an object and the onset of the articulation of its name, a repetition priming effect was obtained but no blocking effect. Experiment 3 showed that the blocking effect for speech onset latencies generalized to new, previously unnamed lexical items. We propose that the blocking effect is due to refractory behaviour in the semantic system.

Selecting words from the mental lexicon is a core task in language production. Most current theories of lexical retrieval distinguish between the selection of semantic–syntactic units (sometimes called lemmas) and the retrieval of the corresponding word forms (e.g., Caramazza, 1997; Dell, 1986; Dell, Schwartz, Martin, Saffran, & Gagnon, 1997; Levelt, Roelofs, & Meyer, 1999; Rapp & Goldrick, 2000). We refer to these processing stages as lexical–semantic and phonological retrieval, respectively. We report experiments using a semantic blocking paradigm that has been designed to investigate the activation and selection of lexical items at the stage of lexical–semantic processing. The paradigm is a single object naming paradigm, where participants on successive trials name objects belonging either to the same semantic category (e.g., fish, mouse, snake, etc.) or to different categories. The naming latencies and

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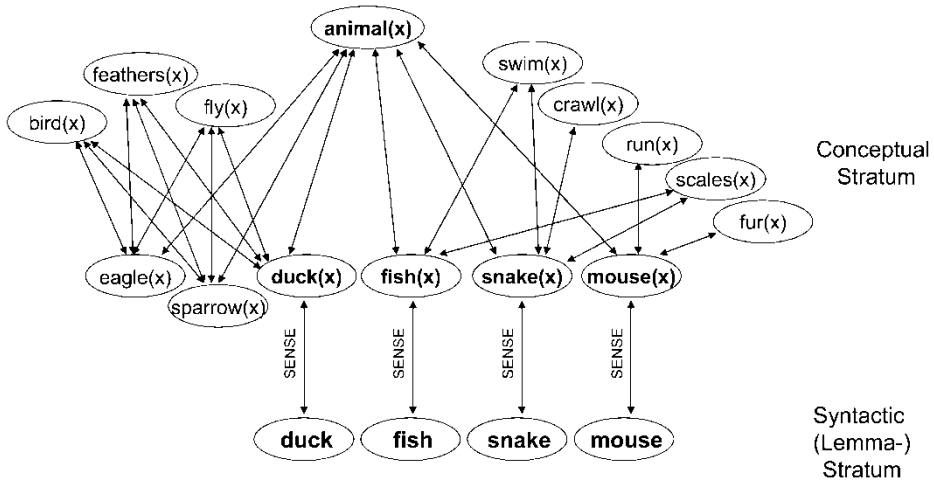
error rates found in semantic blocking experiments show that the retrieval of several object names from the same semantic category (homogeneous context) is more effortful and error prone than the retrieval of object names from multiple, distinct semantic categories (heterogeneous context; e.g., Damian, Vigliocco, & Levelt, 2001; Kroll & Stewart, 1994; McCarthy & Kartsounis, 2000; Wilshire & McCarthy, 2002). In patient studies, the temporal inaccessibility of lexical representations—as a result of the repeated retrieval of names from the same semantic category—has sometimes been referred to metaphorically as “refractory effect” or “refractoriness” (e.g., Forde & Humphreys, 1997). We adopt these terms to refer to access difficulties arising when speakers retrieve several members of the same semantic category within a short period of time. We do not make any claims as to the neural substrates of these access difficulties.

Interestingly, experimental studies and speech error analyses have yielded no evidence for a disadvantage of semantically related over unrelated items when speakers produce pairs or triplets of object names (e.g., “fish and mouse”) as part of one utterance (Hermens, Meyer, & Levelt, 2002; Levelt, 1989). The empirical issue addressed in the present research is under which conditions the retrieval of a lexical item hinders the subsequent retrieval of semantically related items and under which conditions there is no such refractory effect. We hypothesize that a refractory effect should arise whenever a semantic category node (e.g., *animal* for the items fish, mouse, or snake) becomes highly activated and remains so while other items of the category are being retrieved. As we explain below, in such a situation the members of the category become potent competitors to each other, which hinders target selection. We report three experiments testing, and confirming, predictions derived from this hypothesis.

In the remainder of this Introduction, we review the representations and processes underlying lexical-semantic encoding, and we present previous findings from speech error analyses, multiple object naming, and semantic blocking experiments, which, as indicated above, appear to be inconsistent. We put forward our refractoriness account of these findings and, subsequently, test the implications of this account. We adopt the model of lexical access proposed by Levelt, Roelofs, and Meyer (1999) and computationally implemented as WEAVER++ (Roelofs, 1992, 1997) as our working model. However, the arguments we put forward can be detailed in a similar fashion in other models of lexical retrieval (e.g., Dell, 1986; MacKay, 1987).

## Lexical-semantic activation and selection in word retrieval

The semantic level of the mental lexicon is commonly viewed as a network structure, consisting of nodes and connections between them. This structure reflects various types of semantic relations among lexical entries, such as common category membership, synonymy, and associative relations (e.g., Levelt et al., 1999; Rapp & Goldrick, 2000). In the WEAVER++ model (Levelt et al., 1999; Roelofs, 1992, 1997) a lexical-semantic entry consists of a lexical concept node, which is linked to semantic feature and category nodes, and a lemma node, which specifies the syntactic properties of the word (e.g., word class). The lexical concept and lemma node of a lexical entry are linked bidirectionally, yielding a combined semantic-syntactic representation (see Figure 1). Meaning-related lexical concepts, for instance *duck*



**Figure 1.** Fragment of the conceptual and syntactic strata, as assumed in WEAVER++ (adapted from Roelofs, 1992, and Levelt et al., 1999). Note that the arrows represent the flow of activation in the network rather than types of connection. Different types of relations exist between lexical concepts and their feature nodes, such as *is-a*, *can* and *has*. For the sake of readability, not all connections among related nodes are presented.

or *sparrow* in Figure 1, are linked to shared semantic features, such as “has feathers” (see Roelofs, 1992) and to a common category node.

Each lexical concept node has a representational counterpart on the lemma level. As a result, patterns of activation in the semantic feature network are merged in a set of coactivated lexical concepts and their associated lemma nodes (see Figure 1). Virtually all models of lexical retrieval, including WEAVER++, distinguish between the activation of units and their selection as part of an utterance plan (e.g., Dell, 1986; Levelt et al., 1999; for further discussion see also Bloem & La Heij, 2003; Morsella & Miozzo, 2002). In WEAVER++, the *selection* of a target representation occurs at the lemma level. The time required to select a lemma depends on the activation level of the target lemma relative to the sum of the activation of all competing lemmas.<sup>1</sup> Lexical coordinates (i.e., members of the same semantic category) activate each other via their shared feature nodes and the shared category node. It should therefore be more difficult to select a target in the presence of an activated competitor from the same semantic category than in the presence of an activated unrelated competitor (see Roelofs, 1992). This prediction has been confirmed in picture–word interference experiments, where participants name pictures while hearing or seeing distractor words that are lexical coordinates of the target word or are unrelated to the target. Compared to unrelated distractors, lexical coordinates delay the naming response, presumably because they act as more potent competitors during target selection (Caramazza & Costa, 2001;

<sup>1</sup>Other models assume functionally similar mechanisms, such as threshold-based selection (e.g., Schade, 1999). There are also alternative ways of modelling lexical competition at the level of lemma or word nodes, for instance by postulating lateral inhibition whereby highly activated nodes are potent inhibitors of less activated nodes. Node selection is prolonged when multiple nodes have similar levels of activation and inhibit each other (Schade, 1999; Stemberger, 1985; see also Wheeldon & Monsell, 1994).

Damian & Martin, 1999; La Heij, Dirks, & Kramer, 1990; Roelofs, 2001; Schriefers, Meyer, & Levelt, 1990; Starreveld & La Heij, 1995, 1996).<sup>2</sup> Below we propose a similar account for semantic blocking effects.

## Paradigmatic and syntagmatic aspects of lexical retrieval

Lexical retrieval processes have been studied primarily using single object naming tasks. However, by default, language production involves the retrieval of multiple lexical entries that have to be inserted into an utterance plan. In linguistic terms, the lexical entries competing for selection at a given slot of the utterance are in a *paradigmatic* relation, while items occupying successive slots in an utterance are in a *syntagmatic* relation (Saussure, 1916/1983). In psycholinguistics, these relations are mirrored in the “slot-and-filler” notion of utterance planning (e.g., Garrett, 1975, 1988). Most experimental studies of single word production, including those reviewed above, have focused on the paradigmatic dimension of the selection process. Less is known about the syntagmatic coordination of lexical retrieval processes as it occurs when speakers produce several words as part of one utterance (e.g., “duck, saw, chair bus”); but see Levelt & Meyer, 2000).

Analyses of errors occurring in spontaneous speech provide strong support for slot-and-filler theories of utterance generation. Word exchange errors, such as “writing a mother to my letter” instead of “writing a letter to my mother” (see Dell, 1986, p. 285), suggest that inserts for several slots can be simultaneously active. Interestingly, the words involved in contextual, syntagmatic speech errors (exchanges, anticipations, perseverations) are rarely semantically related though they commonly belong to the same syntactic category (nouns in the example; Levelt, 1989; Roelofs, 1992). By contrast, the target and intrusion in noncontextual, paradigmatic word errors (e.g., blends, word substitutions) are very likely to be closely semantically related (e.g., doctor–nurse; Dell & Reich, 1981). This suggests that semantic competition affects the paradigmatic selection of single lexical items but not the syntagmatic combination of several coactivated lexical entries.

This conclusion receives some support from experimental studies. Using the picture–word interference paradigm, Meyer (1996) demonstrated that prior to the initiation of a phrase such as “the arrow and the bag”, speakers often selected the lemmas of both nouns (see also Griffin, 2001; but see Ferreira & Swets, 2002; Meyer, 1997). During lemma selection, one might expect to see interference between semantically related words co-occurring in a phrase. However, in an independent series of experiments, this prediction was not borne out: Hermens, Meyer, and Levelt (2002) asked participants to name triplets of objects with semantically related or unrelated names in complex noun phrases, such as “cat, snake, fish” or “cat, knife, chair”. In order to determine the retrieval times for the object names, they measured the speech onset latencies,

<sup>2</sup>The semantic inhibition effect is contingent on the type of relationship between target and distractor: Semantic inhibition is found for semantic coordinates at any level of categorization (within-level inhibition at subordinate, basic, and superordinate level; Vitkovitch & Tyrell, 1999; Wheeldon & Monsell, 1994), but semantic associates or semantic distractors from a different level of categorization can facilitate naming (across-level facilitation; Costa, Mahon, Savova, & Caramazza, 2003; Vitkovitch & Tyrell, 1999). We use the term “competitors” to refer to within-level lexical coordinates of a target.

speech durations, and the time speakers looked at each object. None of these variables was found to be systematically affected by the relationship between the items.

Thus, it appears that in utterance generation several lexical units can be coactivated but that the selection processes for successive words are largely independent of each other. This may be the result of a powerful serial ordering mechanism as proposed, for instance, by Dell, Burger, and Svec (1997). Their model includes a network of stored lexical representations and a timing network consisting of nodes for past, present, and future representations. The timing network induces strong activation of the current lexical representation, rapid deactivation of past representations and some preactivation of future representations (see also MacKay, 1987; Schade, 1999, for related timing mechanisms). In normal utterance production the activation and decay rates of past, present, and future units are apparently set such that the current unit clearly dominates, and mutual interference between successive words is minimal even when the words are semantically related and the corresponding lexical units activate each other via a shared category node.

### Refractory effects in word retrieval: The semantic blocking paradigm

The absence of sizeable syntagmatic semantic effects in studies of phrase production contrasts sharply with the robust semantic effects obtained in the semantic blocking paradigm, a single object naming paradigm, which was first introduced by Kroll and Stewart (1994, Exp. 1). In their study, participants named lists of pictures and lists of the corresponding printed picture names. Each list included 30 items from two to four different semantic categories. The items were either blocked by category or randomized. Semantic blocking did not affect the latencies for word naming, but the mean latency object naming was longer (by 36 ms) in blocked than in randomized lists. The interaction of stimulus modality (word, picture) and semantic blocking suggests a selective effect of semantic blocking on lexical-semantic retrieval processes but not on the retrieval of word forms. Kroll and Stewart proposed that the semantic blocking effect in picture naming arose because the selection of a target lexical representation was more difficult in the context of semantically similar than of dissimilar items.

Damian et al. (2001) pointed out that the blocking effect could also arise at the level of visual or nonlinguistic conceptual processing because the lists used by Kroll and Stewart (1994) included visually similar items, such as "jacket" and "shirt". Damian et al. controlled for effects of visual similarity by repeatedly presenting the same small sets of visually dissimilar category exemplars (*cyclic* semantic blocking). Each homogeneous and heterogeneous set consisted of five objects that were presented eight times each (e.g., "cat", "mouse", "fish", "duck", "cat", "spider", "mouse", . . . or "shoe", "lamp", "duck", "scissors", "lamp", "bus", . . .). The semantic blocking effect observed by Kroll and Stewart was replicated, which implies that, at least in this study, it did not originate on the visual or conceptual level. As in Kroll and Stewart's study, the blocking effect disappeared when participants read out the names of the objects in homogeneous and heterogeneous sets. The blocking effect is thus likely to arise on the lexical-semantic processing level (see also Maess, Friederici, Damian, Meyer, & Levelt, 2002).

In line with this conclusion, Vigliocco, Vinson, Damian, and Levelt (2002) recently showed that the strength of the blocking effect depended on the degree of relatedness among

the semantically related items: It was more pronounced for sets including closely related members of a given category than for sets including less closely related category members. Further evidence for graded semantic blocking effects stems from the observation that some aphasic patients find it more difficult to access closely related semantic competitors of a just-produced word than more distant semantic competitors (Forde & Humphreys, 1995; see also McCarthy & Kartsounis, 2002; Wilshire & McCarthy, 2000).

Forde and Humphreys (1997, p. 397) proposed that “Following their initial activation, representations within a unitary semantic system may become refractory, making access to detailed knowledge difficult” (see also Warrington & McCarthy, 1983, 1987). There are various ways of accounting for refractory effects within models of object naming. Refractory behaviour may result from temporary inhibition of the representation of a just-produced item and its closely related semantic competitors (spreading inhibition; Vitkovitch, Kirby, & Tyrell, 1996; Vitkovitch, Rutter, & Read, 2001). Alternatively, refractory effects may be induced when a just-produced item and its associated feature nodes maintain high levels of activation such that the item acts as a potent competitor in the subsequent selection of related lexical entries (spreading activation; Forde & Humphreys, 1997).

Our own account, exemplified here within the model of lexical access proposed by Levelt et al. (1999), adopts the latter view. It is based on the assumption that members of a common semantic category activate each other via the category node and therefore compete for selection more intensely than do unrelated lexical items. When, for instance, the picture of a cat is to be named, the category node “animal” will become activated and pass some activation on to other members of the category, including any other animals named on preceding trials. These items send activation back to the category node and other category members including the present target. Thus, the coactivated lexical representations compete intensively for lexical selection. This renders the target representation temporarily less accessible and leads to a delay of the naming process compared to semantically heterogeneous contexts, in which activation is spread across multiple category nodes in the semantic system.

Such semantic competition and the ensuing refractory effect should arise each time a speaker names two or more items from the same semantic category. However, when healthy speakers produce phrases including semantically related nouns, the effect may simply be too weak to have observable consequences (but see Ferreira & Firato, 2003). In healthy speakers, the refractory effects may only become observable when, as in the blocking paradigm, speakers access members of the same semantic category on a number of successive trials. Thus, we hypothesized that the semantic interference effect is boosted in the semantic blocking paradigm due to the frequent and repeated retrieval of lexical entries from the same semantic category (see Damian et al., 2001). In this framework, the retrieval problems observed in certain patients and the semantic blocking effect observed in healthy speakers may both be ascribed to the temporary inaccessibility of recently selected representations and their conceptually similar neighbours (Forde & Humphreys, 1997).

Note that although refractory patterns arise in the semantic system, they affect the naming process during lemma selection: Activation in the semantic system is merged in lexical concepts and their corresponding lemma nodes that compete for selection (see Figure 1). Crucially, within this account, it is the paradigmatic dimension of the lexical selection process that is affected by refractoriness resulting from previous selection processes. Its effects should therefore become observable in tasks that require the production of single

nouns as well as in multiple object naming—provided that enough residual activation has accumulated in the system to interfere with the selection of a target at the lemma level.

## The present study

We carried out three experiments using the cyclic version of the semantic blocking paradigm described above (Damian et al., 2001). Thus, in each presentation cycle speakers named four objects (e.g., “duck”, “mouse”, “fish”, “snake”) that belonged either to the same semantic category or to different categories (e.g., “duck”, “saw”, “chair”, “bus”). The order of the items differed across cycles. We tested three predictions following from our refractoriness account of semantic blocking. First, the account entails that refractory effects should be seen only when a semantic category node is highly activated, which should happen only after a substantial number of retrieval processes from the same semantic category. Thus, we expected the effect to be absent in the first presentation cycle and to build up across the following cycles. In Experiment 1 we aimed to replicate the semantic blocking effect and trace its development over repetitions of the materials, which has not been done before. In Experiment 2, we used a novel version of the blocking paradigm: All items of a cycle now were shown simultaneously, and the participants named them as part of one utterance. To determine the processing time per item, we determined not only the speech onset latency and word durations, but also how long each object was looked at. We aimed to investigate whether it was indeed the paradigmatic dimension of the lexical retrieval process that was affected by refractoriness in the semantic system. If this is so, the same pattern of results should emerge as in the classic version of the paradigm, provided that the items are repeated a sufficient number of times. This experiment should illuminate why refractory effects have been found in the semantic blocking paradigm but not in studies of phrase production; our hypothesis is that this is due to the absence of item repetition in the latter paradigm. In Experiment 3, we investigated whether refractory effects would generalize to new, previously unnamed items of the same semantic category. This is a test of our key assumption, which is that the refractory effect arises because of the high activation level of the common category node and all associated category members. Though this may appear not implausible, there is so far no empirical evidence to support this assumption.

## EXPERIMENT 1

### Method

#### *Participants*

Undergraduate students from the University of Birmingham participated in the experiment in exchange for course credits.

#### *Materials*

The materials consisted of 32 line drawings, including 4 objects each from four semantic categories (animals, tools, vehicles, furniture) and 16 filler objects. The line drawings were selected from a picture gallery provided by the Max Planck Institute for Psycholinguistics, Nijmegen. The pictures were scaled to fit into frames sized  $2.7^\circ \times 2.7^\circ$  when seen from the participant's position, approximately 60 cm from the screen. The pictures were presented at the centre of the screen.



All object names were monosyllabic (see Appendix A) with a mean frequency of 36.75 occurrences per million (COBUILD database, University of Birmingham and Collins). Most experimental items were taken from the set used by Damian et al. (2001), which had been tightly controlled for visual similarity. However, that study was conducted in Dutch, and we had to eliminate four objects because their names in English had more than one syllable. We selected four new items (printed in italics in Appendix A), attempting to maintain minimal levels of within-category visual similarity. The fillers were selected to form four sets with onset-related names (e.g., bell, bean, boot, bowl; the other onset consonants were /t/, /s/ and /k/).<sup>3</sup> The objects from the semantic sets were combined to form four homogeneous and four heterogeneous sets, with the latter sets including one item each of each semantic category. Similarly, the four sets of objects with onset-related names were combined to form four phonologically homogeneous sets and four phonologically heterogeneous sets. The items in these sets were meant to be semantically unrelated. However, due to an error one heterogeneous filler set included semantically related items (sock, tie, and boot). In total 16 sets were created. The phonologically homogeneous and heterogeneous sets were used as filler sets to alternate with the semantically homogeneous and heterogeneous sets. Details as to the order of presentation are given below.

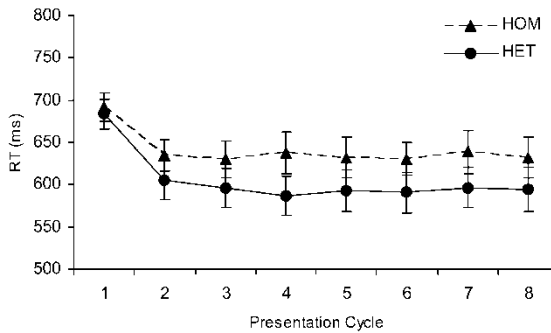
### *Apparatus*

The experiment was controlled by the Nijmegen Experimental SetUp (NESU) Software. Reaction times were registered automatically by a voicekey (HASOMED Nesu-Box 2) using a Sony ECM-MS907 microphone. The participants' responses were simultaneously recorded on a MiniDisc recorder.

### *Design*

The variables context (homogeneous, heterogeneous) and presentation cycle (eight levels) were varied within participants. Based on the eight sets of semantically homogeneous and heterogeneous objects, eight lists of trials were created, each including eight presentation cycles of a set (32 trials). Similarly, eight lists of trials were created from the filler sets, including four phonologically homogeneous (onset-related) lists and four phonologically heterogeneous lists. Each presentation cycle consisted of four successive trials, on each of which one object was shown. The last object of a cycle was never the same as the first of the next cycle to avoid repetition of items on successive trials. In each list of presentation cycles, each object occurred twice on each position within a cycle (i.e., as first, second, third, or fourth object of a cycle). Successive cycles never included the same object in the same position. Each test block consisted of 128 trials, including two semantically homogeneous (sem-hom) and two phonologically heterogeneous lists (phon-het), or two semantically heterogeneous (sem-het) and two phonologically homogeneous (phon-hom) lists. Homogeneous and heterogeneous lists were presented in alternating orders within and between blocks. For instance, a participant would see the lists of the type sem-hom, phon-het, sem-hom, phon-het in the first block and the lists of the type sem-het, phon-hom, sem-het, phon-hom in the second block. The objects used in different list types are specified in Appendix A. The lists were assigned to experimental blocks according to a Greco-Latin square design.

<sup>3</sup>The purpose of the filler items, apart from separating test sets including the same items, was to assess effects of phonological homogeneity on naming latencies and gaze durations. We obtained evidence for phonological facilitation in Experiment 1 but not in Experiment 2. We interpret this as the result of strategic preparation for object naming, which appeared to occur when the items were presented sequentially but not when they were shown simultaneously. These results are not directly relevant to the purpose of the present paper and are therefore not reported in detail.



**Figure 2.** Experiment 1: Mean response times (RT) by context (homogeneous, hom vs. heterogeneous, het) and presentation cycle. The error bars represent one standard error.

### Procedure

Prior to the experiment, participants were given written instructions about the naming task and studied a booklet including pictures and the names of all objects occurring during the experiment. The participants were asked to use the names listed in the booklet and to name each object using a bare noun (e.g., “cat”). In a practice block, they named each object once. On each trial a fixation point was presented at the centre of the screen for 800 ms. Then the screen went blank for 100 ms, and subsequently the target was shown for 1,100 ms. Each trial ended with a blank interval of 650 ms.

### Results and discussion

Data from 3.9% of the experimental trials were excluded because participants hesitated or misnamed an object or because of technical errors. There were no systematic effects of the variables context or presentation cycle on error rates. Valid reaction times from all critical trials were submitted to an analysis of variance (ANOVA) including the within-participants variables context (two levels) and presentation cycle (eight levels), using participants as a random factor.<sup>4,5</sup>

Figure 2 displays the response times in each context over the eight presentation cycles. The ANOVA revealed highly significant main effects of context,  $F(1, 15) = 48.73$ ,  $MSE = 1,639$ ,  $p < .001$ , and presentation cycle,  $F(7, 105) = 23.27$ ,  $MSE = 941$ ,  $p < .001$ . The interaction was also significant,  $F(7, 105) = 2.44$ ,  $MSE = 513$ ,  $p < .05$ ;  $F(3.881, 58.210) = 2.44$ ,

<sup>4</sup>Some analyses of the effects of presentation cycle revealed violations of the sphericity assumptions. We report uncorrected degrees of freedom ( $df$ ) throughout the text when both corrected  $df$  values and uncorrected  $df$  values yielded significant  $F$  values (at  $p < .05$ ). When only the uncorrected, but not the corrected,  $df$  values yield a significant  $F$  value (at  $p < .05$ ) we report uncorrected and corrected  $df$  values and significance levels.

<sup>5</sup>We did not carry out item analyses because the number of items was small and because they were carefully selected to meet a number of criteria rather than being randomly selected from an item pool. Note that we show the existence of the semantic blocking effect, its development over presentation cycles, and the generalization of the effect to new items for two independent item sets. Thus we empirically demonstrate that our main findings can be replicated in different item sets.

$MSE = 925$ ,  $p = .058$ , using Greenhouse–Geisser-corrected degrees of freedom. As Figure 2 shows there was no effect of context on the first presentation cycle. The blocking effect only emerged with the second cycle and was stable thereafter. When we excluded the first presentation cycle from the analysis, the effect of presentation cycle and its interaction with context vanished (both  $F_s < 1$ ), and we only obtained a highly significant effect of context,  $F(1, 15) = 58.98$ ,  $MSE = 1,456$ ,  $p < .001$ .

Experiment 1 replicated the semantic blocking effect obtained by Damian et al. (2001) and Damian (2003) and demonstrated that the effect only emerged after the first presentation of the homogeneous and heterogeneous sets and then remained stable throughout. More specifically, the repetition priming effect observed for heterogeneous sets appeared to be attenuated by the semantic relatedness of the objects in the homogeneous context.<sup>6</sup> Wilshire and McCarthy (2002) and McCarthy and Kartsounis (2000) reported results from investigations of the naming performance of two nonfluent aphasic patients, BM and FAS, which are related to our findings. The patients misnamed significantly more objects in semantically homogeneous than in heterogeneous contexts, particularly at fast presentation rates. Wilshire and McCarthy (p. 172) reported that this blocking effect was accompanied by a decrease of error rates over successive presentations, especially from the first to the second presentation. Unfortunately the authors conducted no combined analyses of blocking and repetition effects, which might have revealed interactive effects of repetition and blocking on the error rates of the two patients (see also McCarthy & Kartsounis, 2000, p. 492f).

A criticism sometimes raised against the semantic blocking paradigm as a means of studying lexical–semantic processes is that the blocking effects may arise earlier, during the visual–conceptual analysis of the items, rather than during lexical processing. One might argue that it is perhaps more difficult to discriminate between items belonging to the same semantic category, which are likely to share visual features, than between items belonging to different semantic categories. As noted above, the items used in the present experiment were selected to be as dissimilar as possible. For 12 of the 16 items we used, Damian et al. (2001) collected similarity ratings, which revealed that the items in homogeneous sets were, on average, not judged to be more visually similar than those in heterogeneous sets. In addition, the absence of a blocking effect during the first presentation of the materials argues against the allocation of the blocking effect at the visual–conceptual level: It is difficult to see why an effect of visual similarity would be absent at first and arise after the first presentation of the materials. Instead, one might expect to see the opposite pattern—visual similarity among items should be more influential at the beginning of a block, when the participants are uncertain which features discriminate between the objects, than after they have become more familiar with the objects. For a supplementary experiment with eight participants we selected items that were semantically as well as visually highly similar objects (e.g., shirt, blouse, coat, jumper; see Appendix B). We only included four presentation cycles because Experiment 1 of the present study had shown that blocking effects emerge after the first presentation cycle

<sup>6</sup>Note that many naming experiments, including the present one, incorporate an initial familiarization phase, for example by asking participants to first study a picture booklet of the material. It is likely that as a result of this familiarization, participants were already slightly faster on the first presentation of the sets than when they had not gone through the pre-exposure phase. Crucially, such pre-existing repetition priming effects should affect all items in a similar fashion.

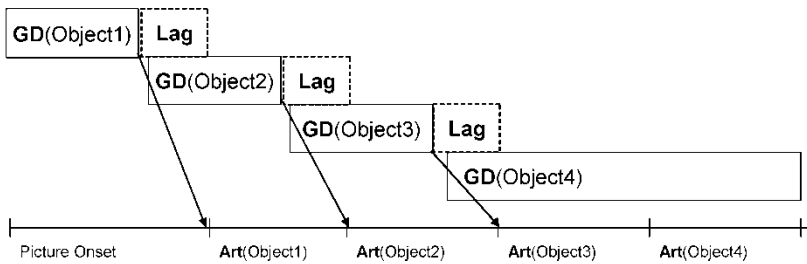
and remain stable thereafter. Using the visually similar items we found a context effect in the first as well as all following repetitions, resulting in significant main effects of context,  $F(1, 7) = 15.24$ ,  $MSE = 3,335$ ,  $p < .01$ , and presentation cycle,  $F(3, 21) = 24.93$ ,  $MSE = 2,075$ ,  $p < .001$ , but no significant interaction of context and presentation cycle. These findings support our assumption that semantically and visually similar sets should produce a different pattern of blocking effects across presentation cycles than should semantically similar, visually dissimilar sets.

## EXPERIMENT 2

In all semantic blocking experiments that we know of the items were presented individually on successive trials. By contrast, in the phrase production experiments by Hermens et al. (2002) the participants saw several objects with semantically related or unrelated names simultaneously. We have suggested in the Introduction that semantic blocking effects may be caused by semantic interference from residual activation in the category and feature nodes of the semantic system. We have argued that such refractory effects affect the paradigmatic dimension of the lexical retrieval process while the syntagmatic coordination of successive retrieval processes remains largely unaffected (Dell et al., 1997). Specifically, we have argued that Hermens et al., in their multiple-object naming study, failed to find semantic interference effects in related object sets because refractory effects had not been sufficiently augmented in their experiments, in which each set was presented only once.

The goal of Experiment 2 was to determine whether a semantic blocking effect would be obtained when speakers see all items of a set simultaneously and name them as part of one utterance. We applied the same design as in Experiment 1, except that the items of a set were now presented simultaneously on only 8 instead of 32 trials. On each trial, the participant produced a complex noun phrase such as “chair, bed, desk, lamp” (see Appendix A). As in Experiment 1, we measured speech onset latencies, but since the participants produced four object names in succession, the overall naming latency did not provide information about the processing times for the individual object names. Therefore, we recorded the participants’ eye movements and determined when and for how long they looked at each object. A number of studies have shown that speakers naming several objects look at each of them in the order of mention (e.g., Griffin, 2001; Griffin & Bock, 2000). Typically, the eyes run a little ahead of the overt speech—that is, speakers move their eyes to the next object before articulating the name of the current object (see Figure 3). The gaze duration for an object that is about to be named (i.e., the time a speaker spends looking at the object) depends on the time required to retrieve conceptual and semantic–syntactic information about the object and to retrieve the phonological code for its name (e.g., Griffin, 2001; Meyer, Sleiderink, & Levelt, 1998; Meyer & van der Meulen, 2000; for reviews, see Griffin, 2004; Meyer & Lethaus, 2004). As Meyer, Roelofs, and Levelt (2003) have shown, the speakers’ eyes usually remain on a target object until its name has been planned to the level of phonological form. This leaves a temporal lag between the end of the gaze on an object and the onset of the articulation of its name. During this lag, speakers move their eyes on to the next object and retrieve the phonetic and articulatory codes of the first object’s name.

For each trial of Experiment 2, we determined the overall naming latencies (RT), the gaze duration for each object and the lag between the end of the inspection of the object and the



**Figure 3.** Schematic overview of the temporal coordination of gaze durations (GD) and articulatory word onsets (Art) in a multiple-object naming task.

onset of its name. Given that we allocate the effects of semantic blocking at the lemma level, we expected blocking to affect overall reaction times and gaze durations but not the eye–speech lags. In addition to semantic blocking effects, we expected repetition effects. As the participants become more familiar with the materials, the speed of visual–conceptual, lexical and postlexical encoding processes should increase (e.g., Cave, Bost, & Cobb, 1996; Schacter, Delaney, & Merikle, 1990; Wheeldon & Monsell, 1992). Thus naming latencies, gaze durations, and lags should decrease across repetitions.

We also determined the intervals between successive word onsets (hereafter called word durations) as an indicator of speech rate. Speakers probably planned the second, third, and fourth object name while articulating the preceding names. It seemed likely that the time required for articulation of an object name would often exceed the planning time for the next name. Therefore, no semantic blocking effect on word durations was expected (see also Damian, 2003). One might, however, expect the word durations to decrease across repetitions due to enhanced articulatory practice.

## Method

### *Participants*

Undergraduate students from the University of Birmingham participated in the experiment in exchange for course credits. They had not participated in Experiment 1.

### *Materials*

The same experimental and filler materials were used as in Experiment 1. Again, the objects were scaled to fit frames sized  $2.7^\circ \times 2.7^\circ$ . The midpoint-to-midpoint distance between them was  $8^\circ$ .

### *Apparatus*

The same equipment was used as in Experiment 1. Eye movements were recorded using an SMI EyeLink-Hispeed 2D eye tracking system with a sampling rate of 250 Hz. The spatial accuracy of the eye tracker was about  $0.1^\circ$ . The participants' responses were recorded onto an external computer.

### *Design*

The variables context (homogeneous, heterogeneous) and presentation cycle (eight levels) were varied within participants. The same lists of trials were used as in Experiment 1 but the four objects

of a set were now shown simultaneously. Each list included the same eight presentation cycles of a set as those in Experiment 1, yielding parallel presentation schemes for both experiments that differed only in the timing of stimulus presentation (now simultaneous) and in the number of trials per list (eight trials). Each test block now consisted of 32 trials.

### *Procedure*

As in Experiment 1, participants first studied the picture booklet listing the materials and named all pictures once in a practice block. Then the helmet of the eye-tracker was mounted, and the system was calibrated. Each trial began with a fixation point that was presented at the position of the leftmost object for 800 ms; then the screen went blank for 100 ms, and then the target set was shown for 4,400 ms, which is four times the presentation time used for a single object in Experiment 1. Each trial ended with an intertrial interval of 300 ms.

Participants were instructed to name the objects presented on the screen without “and” or articles (“the”, “a”, or “an”). They were asked to name the objects as accurately and as fluently as possible.

### *Data analysis*

Based on the speech recordings obtained during the experiment and on literal utterance transcriptions, the onset time for each word of each utterance was determined relative to the picture onset using an automatic speech recognition system for British English (HTK, Hidden Markov-Model Tool Kit). The onset of the first word of an utterance was taken as a measure of the overall naming latency. The duration for each of the first three words was defined as the time periods between successive word onsets. Utterances including dysfluencies or audible pauses between words were excluded from the analyses as erroneous responses.

For the analyses of the speakers' eye movements, the positions and durations of all fixations were determined using SMI software. As noted, the four target objects appeared next to each other, centred in squares sized  $2.7^\circ \times 2.7^\circ$ . We defined all fixations in any of the four object areas as pertaining to that object. The onset times of fixations starting before and ending after picture onset were set to zero. Successive fixations on the same object constituted a gaze to that object. Gaze duration was computed as the time interval between the onset of the first fixation and the offset of the last fixation of a gaze. The gaze duration for the fourth (rightmost) object of each trial was often much longer than the gaze duration for any of the preceding objects because the participants' eyes remained on the location of that object until the next fixation point appeared on the screen. Therefore, we only included the gaze durations for the first three objects in the analyses. The eye-speech lag for an object was defined as the time interval between the offset of a gaze to the object and the onset of the articulation of its name. This variable could not be computed for the fourth object either because there was no following object to be inspected. Since we did not include the gaze duration and eye-speech lag for the fourth object in the analyses, we did not include a measure of the duration for the name of the fourth object either, in order to base all analyses on comparable data sets. Thus, we computed the speech onset latency (i.e., the onset of the first word) for the entire utterance, and the mean gaze duration, eye-speech lag, and word duration averaged across the first three objects of each sequence.

## **Results and discussion**

A total of 2.7% of the critical trials were excluded because of dysfluent or incorrect utterances. ANOVAs showed a main effect of context,  $F(1, 15) = 7.35$ ,  $MSE = 313$ ,  $p < .05$ , with significantly more errors in the homogeneous (3.7%) than in the heterogeneous condition (1.6%). Analyses of the viewing patterns showed that, as expected, participants usually

viewed the objects in the order of mention. On 95.4% of the trials, they looked at each object once without skipping any objects or returning to previous objects. The remaining trials were excluded from the analyses. Often these trials coincided with hesitations or naming errors in participants' utterances.

The mean overall naming latencies were longer in the homogeneous context ( $M = 872$ ,  $SE = 42$ ) than in the heterogeneous context ( $M = 819$ ,  $SE = 39$ ), yielding highly significant main effects of context,  $F(1, 15) = 25.53$ ,  $MSE = 7,050$ ,  $p < .001$ , and presentation cycle,  $F(7, 105) = 6.93$ ,  $MSE = 11,055$ ,  $p < .001$ . As we had measured reaction times to *sets* of objects, the average number of valid reaction time observations per participant was small ( $n = 61$ ) compared to the average number of valid reaction time observations obtained per participants in Experiment 1 ( $n = 498$ ). We therefore did not analyse the interaction of presentation cycle and context.

As expected, the word durations were not affected by semantic context,  $F(1, 15) = 2.05$ ,  $MSE = 6,726$ ,  $p = .173$ , but decreased across the presentation cycles,  $F(7, 105) = 6.72$ ,  $MSE = 2,596$ ,  $p < .001$ ; see Figure 4a. The interaction of context and presentation cycle was not significant,  $F(7, 105) = 1.64$ ,  $MSE = 1,685$ ,  $p = .132$ .

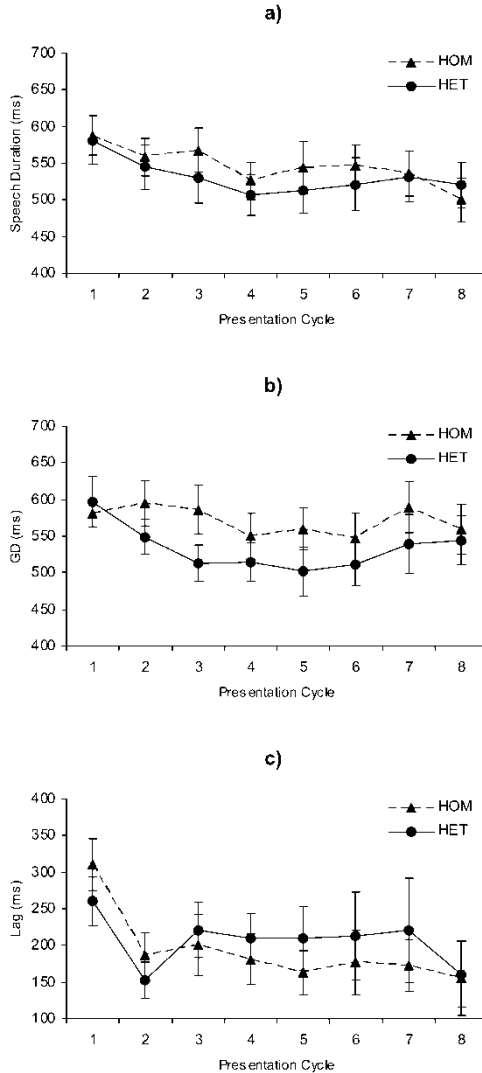
Figure 4b displays the mean gaze duration per object in each presentation cycle of homogeneous and heterogeneous sets. The ANOVA revealed significant effects of context,  $F(1, 15) = 21.96$ ,  $MSE = 3,970$ ,  $p < .001$ , and presentation cycle,  $F(7, 105) = 4.59$ ,  $MSE = 3,260$ ,  $p < .001$ . Their interaction approached significance,  $F(7, 105) = 2.12$ ,  $MSE = 2,944$ ,  $p < .05$ ;  $F(3.989, 59.836) = 2.12$ ,  $MSE = 5,166$ ,  $p = .09$ , using corrected degrees of freedom. In the first presentation cycle the gaze durations for homogeneous and heterogeneous sets were very similar (see Figure 4b). Paralleling the results obtained for the naming latencies in Experiment 1, the interaction of context and presentation cycle was not significant when the data from the first presentation cycle were excluded from the analysis,  $F(6, 90) = 1.14$ ,  $MSE = 2,544$ ,  $p = .346$ . The effect of context remained,  $F(1, 15) = 26.22$ ,  $MSE = 4,239$ ,  $p < .001$ , as did the effect of presentation cycle,  $F(6, 90) = 2.99$ ,  $MSE = 3,094$ ,  $p = .01$ . Thus, for the gaze durations we obtained the same pattern of results as that for the speech onset latencies in Experiment 1.

The eye–speech lag (averaged across the first three objects of each display) was affected by presentation cycle only,  $F(7, 105) = 4.84$ ,  $MSE = 9,767$ ,  $p < .001$ ; see Figure 4c. The data show a strong repetition priming effect with a substantial shortening of the lag from the first to the second presentation cycle in homogeneous and heterogeneous sets. A separate ANOVA excluding the first presentation revealed no significant effects of context, presentation cycle or their interaction.

Thus we found evidence for semantic blocking in the speech onset latencies and the mean gaze durations per object, but not in the eye–speech lags. This supports the localization of semantic blocking effects at the level of lexical–semantic processing. Furthermore, the results demonstrate that semantic blocking effects can be obtained when the objects of a set are presented simultaneously. Finally, the results demonstrate that the effects only arise after all items have been seen and named at least once. Our results imply that repeated access to the same semantic category, rather than sequential presentation of the items, is crucial for obtaining a semantic blocking effect. As noted above, studies of lexical access in connected speech (Hermens et al., 2002) and analyses of speech errors have yielded no evidence that the syntagmatic coordination of lexical retrieval processes is affected by the semantic similarity

of the object names. The absence of semantic blocking effects in the first presentation cycle of the present experiment corroborates these findings. The fact that very similar patterns of results were found in Experiments 1 and 2 supports our view that semantic blocking affects the paradigmatic dimension of the lexical retrieval process (the selection of items for a given utterance position), leaving the syntagmatic coordination of the retrieval processes largely undisturbed.

Presentation cycle affected both the gaze durations for individual objects and the lags between gaze offset and articulation onsets. This is in line with Wheeldon and Monsell's



**Figure 4.** Experiment 2: (a) Mean speech durations, (b) gaze durations (GD), and (c) eye-speech lags by context and presentation cycle. The error bars represent one standard error.



(1992) conclusion that repetition priming in picture naming affects not only postlexical articulatory planning but also lexical-semantic processing, more specifically the mapping from semantic to phonological representations. Presumably, the repetition priming for gaze durations also reflects facilitation at the level of object recognition (Schacter et al., 1990).


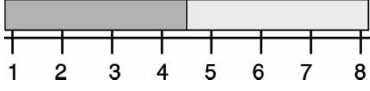
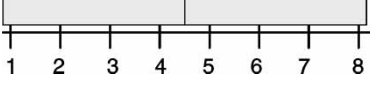

### EXPERIMENT 3

Experiments 1 and 2 established that the semantic blocking effect arose only after the participants had seen and named the items of a set once. As explained above, members of a homogeneous set share semantic features and are linked to a common superordinate node. Through these nodes they activate each other during the course of a presentation cycle and therefore compete more strongly for production than do members of heterogeneous sets. Therefore lemma selection is slower in homogeneous than in heterogeneous sets. This account relates the semantic blocking effect to general patterns of connectivity in the mental lexicon (see, for instance, Levelt et al., 1999; Roelofs, 1992). It predicts that the effect should not be confined to the repetition of specific members of homogeneous and heterogeneous sets alone but should generalize to new members of the same semantic category. Alternatively, one might propose that lexical representations undergo a brief period of self-inhibition after selection (Dell, 1986), which, for some reason, might be more difficult to overcome in a semantically homogeneous than in a semantically heterogeneous context. Such an account would predict no generalization of the blocking effect to new items.

To assess whether the blocking effect would generalize to new items, we selected four new members of each of the four semantic categories tested in Experiments 1 and 2 and formed four new homogeneous and four new heterogeneous sets from these items. We crossed the variable context (homogeneous or heterogeneous) with a new variable, consistency. In the consistent condition, participants saw the same set of items in eight successive presentation cycles, just as in Experiment 1. In the inconsistent condition, they saw one set of items (e.g., four animals or four unrelated items) during the first four cycles and the parallel set (four different animals or four new unrelated items) on the fifth through eighth cycle. One group of participants saw the “old” homogeneous and heterogeneous object sets (i.e., the items already tested in Experiments 1 and 2) on the first four presentation cycles and then changed to the “new” materials. For another group of participants, this order was reversed (see also Table 1). In the consistent condition, the first group of participants saw only the old materials, and the second group saw only the new materials. The items were presented sequentially as in Experiment 1.

Based on the results of Experiment 1, we expected a repetition priming effect and a semantic blocking effect to build up during the first four presentation cycles. The introduction of new items in cycle 5 should, of course, lead to an increase of the latencies relative to the immediately preceding cycles. If the semantic blocking effect generalizes to new items, the difference between homogeneous and heterogeneous sets that we expected to observe in cycles 2 to 4 should prevail on the 5th cycle. If the blocking effect does not generalize to new items, the reaction times for homogeneous and heterogeneous objects in the fifth cycle should be similar to those obtained in the first cycle and should not differ from each other.

TABLE 1  
Design of Experiment 3: Lists tested  
in Groups A and B

Group of participants	List type	
	Consistent	Inconsistent
A	<p><b>old – old</b></p> 	<p><b>old – new</b></p> 
B	<p><b>new – new</b></p> 	<p><b>new – old</b></p> 

## Method

### Participants

Two groups of 12 undergraduate students from the University of Birmingham participated in the experiment in exchange for course credits. They had not participated in Experiments 1 or 2.

### Materials

A set of 32 line drawings was used, including the 16 semantically related objects used in Experiment 1 (Appendix A) and a set of 16 new semantically related objects (four per category; see Appendix C). These two sets are referred to as the “old” and “new” sets, respectively. The mean frequency of the items in the new set was 40.50 occurrences per million in the COBUILD database (compared to 36.75 in the old set). The objects from the old and new sets were combined to form four homogeneous and four heterogeneous sets each, with the latter sets including one item each from each semantic category. Thus 16 sets were created.

### Design, apparatus, and procedure

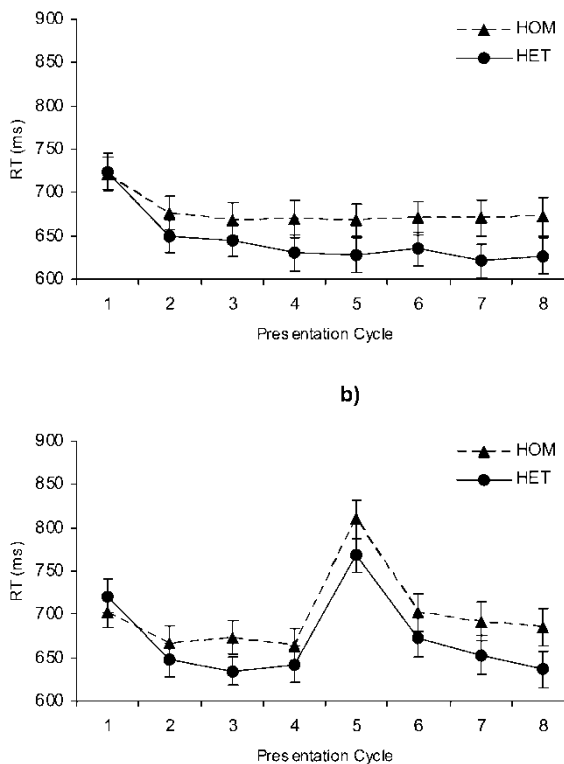
Table 1 gives an overview of the design. The variables context (with two levels) and presentation cycle (with eight levels) were varied within participants, as in Experiment 1. As explained above, these variables were crossed with a new variable, consistency, which was also tested within participants. In consistent sets, the participants saw the same items in eight presentation cycles; in inconsistent sets, they saw one set of items during the first four cycles and a parallel set during the second four cycles.

From the 16 four-item sets described above we generated 32 lists of test materials. Eight lists included only old items, and of these lists four were homogeneous, and four were heterogeneous. Another eight lists (four homogeneous and four heterogeneous) included only new items. These 16 lists

were the consistent lists. The remaining 16 lists were inconsistent lists that included both old and new items. In eight of them (old–new lists), one of the old item sets was tested during the first four cycles, and the parallel new set was tested in the last four cycles. In the remaining eight lists (new–old lists), a new set was tested first, followed by the parallel old set. Each participant saw consistent and inconsistent lists. One group of participants (Group A) saw the old consistent sets and the old–new inconsistent sets. Another group of participants (Group B) saw the new consistent sets and the new–old inconsistent sets (see Table 1). Homogeneous and heterogeneous lists were presented in alternating orders within and between test blocks. Two consistent and two inconsistent sets were included in each block. To prevent participants from predicting the upcoming list type (consistent, eight same-set cycles vs. inconsistent, two times four cycles of different sets) the order of consistent and inconsistent sets was varied between blocks. The apparatus and the procedure were the same as those in Experiment 1.

## Results and discussion

A total of 4.1% of the responses were excluded because the voicekey was activated too early or too late (2.3% of the trials) or because participants had hesitated or named an object incorrectly (1.8% of the trials). The error rate was not systematically affected by any of the experimental variables.



**Figure 5.** Experiment 3: Mean response times (RT) by context and presentation cycle for (a) consistent and (b) inconsistent sets. The error bars represent one standard error.

Figure 5 displays the results separately for consistent sets (top), in which the participants saw the same items in all eight presentation cycles, and for inconsistent sets (bottom), in which new items were introduced in cycle 5. The results for the consistent sets were very similar to those obtained in Experiment 1: We obtained a repetition priming effect and a semantic blocking effect, which was confined to cycles two through eight. In the inconsistent sets, there was also evidence for repetition priming from the first to the following cycles. On cycle 5, the naming latencies sharply rose due to the introduction of new items. Importantly, the semantic blocking effect, which was present from cycle 2 onwards, survived the change of items. In other words, the effect generalized to the new item set.

Though the inspection of the results might suggest otherwise, the ANOVA did not yield a significant interaction of consistency, context, and presentation cycle,  $F(7, 154) < 1$ . We obtained significant main effects of context,  $F(1, 22) = 140.61$ ,  $MSE = 1,190$ ,  $p < .001$ , presentation cycle,  $F(7, 154) = 55.76$ ,  $MSE = 1,353$ ,  $p < .001$ , and consistency,  $F(1, 22) = 51.40$ ,  $MSE = 2,250$ ,  $p < .001$ . The interaction of consistency and presentation cycle was significant,  $F(7, 154) = 59.62$ ,  $MSE = 990$ ,  $p < .001$ , as was the interaction of context and presentation cycle,  $F(7, 154) = 9.31$ ,  $MSE = 849$ ,  $p < .001$ . Figure 5 shows that the context effect was absent in the first presentation cycle and increased in strength across the following cycles. When the results from the first cycle were excluded from the analysis, the interaction of presentation cycle and context was still significant,  $F(7, 154) = 2.52$ ,  $MSE = 730$ ,  $p < .05$ , as was the main effect of context,  $F(1, 22) = 130.81$ ,  $MSE = 1,596$ ,  $p = .024$ . Thus the pattern of results was slightly different from the patterns obtained in Experiments 1 and 2, where no further increase of the strength of the context effect after the first cycle had been observed. Most importantly, the interaction of context and consistency did not reach significance in the analysis over all eight or the last seven presentation cycles (both  $F$ s  $< 1$ ), implying that context effects of comparable strength were obtained in consistent and inconsistent sets.

TABLE 2  
Results of separate ANOVAs on consistent and inconsistent sets in Experiment 3<sup>a</sup>

Sets		<i>Analyses including presentation cycles</i>					
		1-8			2-8		
		<i>df</i>	<i>F</i>	<i>MSE</i>	<i>df</i>	<i>F</i>	<i>MSE</i>
Consistent	Context	1, 22	31.52***	3,102	1, 22	37.15***	30,812
	Cycle	7, 154	32.06***	974	6, 132	1.99	820
	Context × Cycle	7, 154	4.41***	758	6, 132	1.63	669
	Group	1, 22	0.24	89,307	1, 22	0.19	79,804
	Group × Context	1, 22	4.40*	3,102	1, 22	4.52*	3,082
Inconsistent	Context	1, 22	32.29***	2,187	1, 22	35.99***	2,635
	Cycle	7, 154	75.42***	1,369	6, 132	81.94***	1,392
	Group × Cycle	7, 154	5.24***	1,010	6, 132	1.65	900
	Group	1, 22	0.84	86,816	1, 22	1.06	77,668
	Group × Cycle	7, 154	4.22***	1,369	6, 132	3.73**	1,392

<sup>a</sup>Context and presentation cycle were included as within-participants factors and group as between-participants factor. Interactions among variables that are not displayed were not significant.

Note: \* $p < .05$ ; \*\* $p < .005$ ; \*\*\* $p < .001$ .

In further analyses we considered the results from the consistent and inconsistent sets separately (see Table 2). For the consistent sets we replicated the findings of Experiment 1. There were significant effects of context and presentation cycle and their interaction. When the first presentation cycle was excluded from the analysis, the effect of presentation cycle and its interaction with context disappeared; only the effect of context was significant. There were no significant effects of group (A, tested on old items vs. B, tested on new items). Separate analyses for each group yielded parallel results as the overall analyses presented in Table 2. Most importantly, the effect of context was significant in both groups,  $F(1, 11) = 21.34$ ,  $MSE = 4,324$ ,  $p < .001$ , for Group A;  $F(1, 11) = 10.20$ ,  $MSE = 1,880$ ,  $p = .01$ , for Group B. Thus we replicated the basic blocking effect with a new set of materials (see also Footnote 5). There was a marginally significant interaction of group and context (see Table 2), reflecting the fact that the blocking effect was slightly stronger for Group A than for Group B (see above).

For the inconsistent sets, we also found main effects of context and presentation cycle and a significant interaction of these variables when all eight presentation cycles were included. When the first presentation cycle was excluded, the context effect was still significant, but the interaction of context and cycle disappeared, as in the consistent sets (see Table 2). The main effect of presentation cycle was still significant due to the long latencies in cycle 5, where the new items were introduced.

The main effect of group was not significant in the analysis including all or only the last seven presentation cycles. However, as Table 2 shows, the interaction of group and presentation cycle reached significance in both analyses. This is due to the fact that the effect of presentation cycle was slightly more pronounced in Group A, tested on old–new lists,  $F(7, 77) = 40.46$ ,  $p < .001$ , than in Group B, tested on new–old lists,  $F(7, 77) = 38.73$ ,  $p < .001$ .

In conclusion, these results demonstrate that the semantic blocking effect is not confined to the specific items of a homogeneous set but generalizes to new items within the same semantic category. The lexical competition effects observed in semantic blocking seem to be based on general principles of connectivity in the mental lexicon yielding more competition among members of the same semantic category than among unrelated lexical entries.

## GENERAL DISCUSSION

In the experiments reported above we replicated the semantic blocking effect found in earlier studies. In addition, we traced the development of the effect across presentation cycles and separated the effects of item repetition and semantic relatedness: In the first presentation cycle the latencies for semantically related and unrelated sets were very similar. In the second cycle, we saw a substantial decrease in the naming latencies in the heterogeneous condition. This effect can be attributed to repetition priming arising at a number of processing levels, including the recognition of the objects, lexical retrieval, and postlexical processes. In the homogeneous condition, less repetition priming was observed, presumably because the priming effect was counteracted by the semantic blocking effect. As noted in the Introduction, current models of the mental lexicon represent relationships between items in links to shared superordinate and feature nodes. Since related items activate each other via these links they should compete for selection more vigorously than should unrelated items. As predicted, the resulting inhibitory effect only becomes observable after some potentiation, as the development of the blocking effect across presentation cycles shows.

In all earlier semantic blocking experiments, the items were presented individually on successive trials, and the participants named them in single words. Experiment 2 of the present study demonstrated that sequential item presentation or the production of one-word utterances is not critical for obtaining blocking effects. Instead evidence for semantic blocking can also be obtained when the items of a set are presented simultaneously, and speakers name them as part of one utterance. We found evidence for semantic blocking in the speech onset latencies and gaze durations of the objects, but not in the eye–speech lags or word durations. In earlier studies, the gaze duration for an object has been shown to depend on the time required to recognize objects and retrieve their names, whereas eye–speech lag and word duration depend on the time required for postlexical and articulatory processes (for reviews, see Griffin, 2004; Meyer & Lethaus, 2004). Therefore, the confinement of the semantic blocking effect to latencies and gaze durations supports the allocation of the blocking effect at the level of lexical-semantic processing. Specifically, the gaze durations for the objects displayed the same interaction of repetition priming effects and semantic blocking effects as did the reaction times in Experiment 1.

This finding corroborates our hypothesis that refractoriness in the semantic system predominantly affects the paradigmatic dimension of the lexical retrieval process (the selection of an item for an utterance position). Experiments 1 and 2 demonstrate that the predicted semantically based competition indeed arises in single and multiple object naming alike but that it needs some potentiation, through repetition of the items, to become observable. This explains why no evidence for semantic blocking was found in an earlier multiple object naming experiment, in which speakers named sets of semantically related or unrelated objects just once (Hermens et al., 2002), and why no evidence for semantically based competition has been found in analyses of exchange errors.

The most important finding of the current series of experiments is the generalization of the semantic blocking effect to new items. This demonstrates that the effect is not due to postselectional self-inhibition processes that render specific items inaccessible after use. Instead, this result supports our argument that residual activation in the semantic system, resulting from having named an object on a previous trial, interferes with the patterns of activation during ongoing lexical-semantic encoding processes. When repeatedly naming objects from homogeneous object sets, (residual) activation accumulates in the semantic system within a small set of related lexical concepts and their shared category and feature nodes. By contrast, when the object names have been retrieved from heterogeneous semantic contexts the activation is more dispersed. During lexical retrieval, the different activation densities are mapped onto the lemma level, where they establish a high-competition situation in the semantically homogeneous context but a low-competition situation in the semantically heterogeneous context. This renders the selection of the target lemma more difficult in the semantically homogeneous context than in the semantically heterogeneous context. We have referred to this phenomenon as “refractory behaviour”, a metaphor that has first been used in reports of aphasic performance (e.g., Forde & Humphreys, 1997; Warrington & McCarthy, 1983, 1987). As pointed out in the Introduction, refractory behaviour can be induced as a result of spreading activation, as well as through spreading inhibition. In the present paper, we have focused on the residual activation account, which is compatible with our working model of lexical access (WEAVER++; see Levelt et al., 1999; but see, e.g., MacKay, 1987, Schade, 1999, for alternative frameworks).

Our proposal implies that within-category interference arises in a picture naming task whenever competing lemmas activate each other via links to shared nodes. These nodes may be common superordinate nodes or shared features nodes (see Figure 1). Since in our experiments the items belonging to the same semantic category were selected to share few features, the effect was probably carried primarily by the link to the joint superordinate category nodes (see Figure 1). Vigliocco et al. (2002) obtained stronger semantic blocking effects for closely related than for less closely related members of semantic categories. Similarly, in studies of impaired lexical retrieval processes (Forde & Humphreys, 1997; McCarthy & Kartsounis, 2000) refractory behaviour has been shown to spread along a semantic gradient: The patients performed more poorly for sets of semantically closely related items (e.g., “eagle”, “duck”, “sparrow”) than for more distantly related items (e.g., “duck”, “fish”, “mouse”). These results demonstrate that the semantic blocking effect is supported by links to shared features. Whether a blocking effect can be obtained for lexical concepts that only share semantic features (e.g., “has a fur”) but do not belong to the same semantic category (e.g., “fur coat” and “dog”) remains to be seen.

Our account relies on the mutual activation of competing lemmas. It predicts that the repetition of specific items should not be necessary for the development of a semantic blocking effect. Instead, the effect should arise when a small number of items is accessed repeatedly as well as when a larger set of items is accessed once each. Consistent with this prediction Kroll and Stewart (1994) reported a semantic blocking effect using large sets of items that were not repeated; however, as noted, in this study visual similarity among the related items may have contributed to the effect. Further studies are required to assess the importance of item repetition more systematically.

In other paradigms, refractoriness in the semantic system can be induced more rapidly than in the blocking paradigm: Wheeldon and Monsell (1994) used a semantic priming task in which prime words were elicited by definitions and target words by pictures, which the participants named. Wheeldon and Monsell obtained facilitatory priming effects when prime and target were presented on successive trials but inhibitory effects when two trials intervened between prime and target. They allocated the facilitatory effect on the conceptual level and argued that the inhibitory effect was due to lexical competition induced by the recent retrieval of a semantic competitor. Additional research is required to identify the factors determining how quickly refractory effects build up. It is possible that the naming to definition task used by Wheeldon and Monsell forced participants to spend more time processing each item and/or to activate a larger and more diverse set of features than are activated during picture naming. This may have led to a stronger activation of the category node and of other members of the semantic category than that arising after naming of a single picture.

Beyond the picture naming task, there is further evidence for interference effects in the semantic system during the successive retrieval of several same-category exemplars. For instance, in cued recall tasks where participants are asked to retrieve as many items as possible of a given category (e.g., animals), the retrieval of item names becomes more laborious the more items that have been retrieved (Battig & Montague, 1969; see also Nickerson, 1984). Along similar lines, part-set cueing—that is, providing participants with the names of some category exemplars by saying, for instance, “Name as many types of fruit as you can, such as apple and pear”—inhibits the retrieval of further exemplars (see Nickerson, 1984, for a review). Having previously retrieved several category exemplars from memory apparently

blocks or hinders the retrieval of further exemplars (see also Ferreira & Firato, 2003, for related evidence). We do not present the evidence on cued recall in detail here because the picture naming task and the cued recall task differ substantially from each other. Most importantly, in picture naming participants can readily activate a given lexical concept on the basis of the given picture whereas in cued recall it is their task to find and activate several concepts of a given category from memory. As stated above, in picture naming it may need some potentiation—for example, through the repeated retrieval of object names from the same semantic category—to make patterns of refractoriness appear.

In sum, we obtained semantic blocking effects for both sequential and simultaneous item presentation, suggesting that semantic blocking affects the paradigmatic dimension of the lexical retrieval process. We demonstrated that the blocking effect arises only after a given semantic category has been accessed a number of times. Furthermore, we showed that the effect is not bound to the repetition of specific items but generalizes to new items of the tested categories. Our account, which also provides an explanation for refractory patterns in certain patients with impairments of the semantic system, links the semantic blocking effect to general patterns of accruing competition among exemplars from the same semantic category. Because the blocking effect is not just a “special effect” arising in a particular paradigm but is a reflection of a general property of the semantic system, we see the blocking paradigm as a potentially useful tool in further research into the organization and use of the semantic system.

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## APPENDIX A

### List of objects used in Experiments 1 and 2

#### *Semantic sets:*

##### *Homogeneous*

ANIMALS: duck, fish, mouse, snake

FURNITURE: *bed, chair, desk, lamp*

TOOLS: *brush, drill, rake, saw*

VEHICLES: bike, bus, cart, train

*Note:* The items printed in italics were not included in the study by Damian et al. (2001).

##### *Heterogeneous*

duck, *chair*, saw, bus

mouse, *bed, rake*, train

snake, lamp, *brush*, cart

fish, bike, desk, drill

#### *Phonological sets (used as fillers):*

##### *Homogeneous*

/b/: bean, bell, boot, bowl

/k/: can, cake, comb, corn

/s/: sack, safe, sock, sun

/t/: tent, tie, tooth, top

##### *Heterogeneous*

bean, can, sun, tent

boot, corn, sock, tie

bowl, comb, safe, tooth

bell, cake, sack, top

## APPENDIX B

### List of objects used in the experimental supplement to Experiment 1

#### *Homogeneous*

FRUIT: apple, peach, pear, orange

INSECTS: ant, beetle, fly, mosquito

BIRDS: duck, goose, swan, turkey

CLOTHING: coat, blouse, shirt, sweater

#### *Heterogeneous*

apple, beetle, blouse, duck

goose, mosquito, peach, sweater

coat, fly, swan, orange

ant, pear, shirt, turkey

## APPENDIX C

### Additional semantic sets used in Experiment 3

#### *Homogeneous*

ANIMALS: ant, frog, owl, pig

FURNITURE: chest, clock, rug, shelf

TOOLS: axe, broom, nail, wrench

VEHICLES: car, raft, ship, sled

#### *Heterogeneous*

ant, shelf, wrench, car

frog, rug, broom, ship

owl, clock, nail, raft

pig, chest, axe, sled