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Consequences of an inhibition deficit for word production and comprehension: Evidence from the semantic blocking paradigm

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We investigated the semantic blocking effect in picture naming and word–picture matching for two nonfluent aphasic patients who show evidence of a deficit in inhibiting verbal representations (M.L. and B.Q.), one fluent aphasic patient (K.V.), and neurologically intact control participants. In two picture-naming tasks (Experiments 1A and 1B), M.L. and B.Q., relative to controls, showed a greatly exaggerated semantic blocking effect in naming latencies that increased dramatically across repeated presentations. On two corresponding word–picture matching tasks (Experiments 2A and 2B), both also showed an increasing semantic blocking effect, though the effects were not as large nor as consistent as those in naming. The fluent patient, K.V., showed a pattern like controls on both tasks. On an associated word–picture matching task, both M.L. and B.Q. showed results paralleling those of controls. The contrast between the production and comprehension patterns for M.L. and B.Q. supports the conclusion that their exaggerated blocking effect in production arises during lexical rather than semantic selection. We postulate that M.L.'s (and potentially B.Q.'s) production effect is due to difficulties in postselection inhibition, which results in overactivation of lexical representations. This overactivation is likely to be one source of their nonfluency in spontaneous speech.

Keywords: Aphasia; Lexical selection; Inhibition; Production; Semantic blocking.

A number of recent studies have investigated the source of deficits in the production of words in context for patients who show relatively preserved single-word production (Freedman, Martin, & Biegler, 2004; McCarthy & Kartsounis, 2000; Schwartz & Hodgson, 2002; Wilshire & McCarthy, 2002). These patients' spontaneous speech is nonfluent—that is, slow and halting with long pauses between words or phrases, even though individual words may be produced fluently without articulatory distortion. Notably, their speech may not be classically agrammatic, as function words and grammatical markers may be produced at a normal rate (Freedman et al., 2004). Across all of these studies, the hypothesis has been put forward that semantic and lexical representations are largely intact for these patients, accounting for their good single-word production, but that control processes that act on these representations during retrieval are impaired in a manner that affects their production of multiple words. Various hypotheses have been put forward regarding the nature of the damaged control processes—from excessive inhibition of lexical representations (McCarthy &

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Kartsounis, 2000), to difficulty in selecting among activated representations (Wilshire & McCarthy, 2002), to damaged syntactic selection processes (Schwartz & Hodgson, 2002), to deficient semantic short-term memory (Freedman et al., 2004).

It is possible that there are several different control functions that act on lexical representations during production, and that the patients reported by the different researchers have impairments in different functions. On the other hand, it is also possible that the patients have the same underlying impairment, but that the similarity is hidden to some extent by the fact that the patients have been tested on different tasks or because the patients differ in severity such that an effect that shows up in error rates with one patient would only show up in reaction times for another. One task that has been administered to several of these patients is the semantically blocked picture-naming task, in which the naming in succession of several items from the same semantic category is compared to naming the same pictures when presented in mixed category sets. McCarthy and Kartsounis (2000) and Wilshire and McCarthy (2002) showed that their patients demonstrated substantially greater naming errors for the semantically blocked sets. Although Schwartz and Hodgson (2002) did not find an effect of semantic blocking for their patient (N.Q.), she was later found to show a semantic blocking effect in a study by Schnur, Schwartz, Brecher, and Hodgson (2006) when repeatedly naming the items, as had been done in the McCarthy and Kartsounis and Wilshire and McCarthy studies. It should also be noted that all three studies also manipulated the rate at which pictures were presented in terms of the response–stimulus interval. All found that their patients did worse at a fast rate, and McCarthy and Kartsounis and Wilshire and McCarthy showed that the semantic blocking effect was exaggerated at the faster rate.

The semantic blocking effect was interpreted in two rather opposite ways by McCarthy and Kartsounis (2000) and Wilshire and McCarthy (2002). McCarthy and Kartsounis attributed their patient's deficit to "refractory lemma access"—that is, to overly prolonged inhibition of selected lexical representations that spreads to semantically related lexical representations. The refractory access in production is an analogue to the refractory access of semantic representations that Warrington and colleagues (Crutch & Warrington, 2005; Warrington & McCarthy, 1983, 1987) have postulated to explain the increasing error rates from repeated sampling from the same semantic category during word comprehension tasks for some global aphasic patients. As several models of speech production assume that lexical representations are inhibited after production to prevent their reselection (Dell, 1986; MacKay, 1987), it is feasible that brain damage might prolong or exacerbate this inhibition. In order to account for the semantic blocking effect, it is necessary to assume that inhibition spreads to semantically related items and that this inhibition is prolonged for the related items as well. The rate effect and its interaction with semantic blocking follow from the assumption that the overinhibition will eventually dissipate.

Wilshire and McCarthy (2002), on the other hand, suggested that their patient had difficulty in selecting from several highly activated representations. Due to spreading activation, semantic blocking would result in the simultaneous activation of a set of semantically related lexical items. To the extent that lexical selection is a competitive process whereby, for instance, selection of one representation depends on its activation having exceeded that of the nearest competitor by some ratio, strong coactivation should lead to prolonged latencies in production and an increase in errors.[1]

[1] Recently, the claim has been put forward that the competition is not involved in selection at the lexical level, but instead occurs at an output buffer stage (e.g., Mahon, Costa, Peterson, Vargas, & Caramazza, 2007; Miozzo & Caramazza, 2003). This view has been put forward mainly to account for findings from picture–word interference tasks in which the picture name and the word are available simultaneously and could compete for output. It is somewhat difficult to see how this hypothesis could be applied to the semantically blocked naming effect, as one would have to hypothesize that output representations persist across trials. One would assume that participants could clear the buffer at the end of the previous response, given prior assumptions about participants' ability to clear the buffer of irrelevant responses that are available early (Miozzo & Caramazza, 2003).

Wilshire and McCarthy assumed that the activation process proceeded in a normal fashion, but that the patient suffered from damage to some external process that served to resolve the competition and select the correct response. The rate effect and its interaction with semantic blocking were attributed to the decrease in activation of competitors with longer intervals between picture onsets across trials.

Similar to the hypothesis put forward by Wilshire and McCarty (2002), Schnur et al. (2006), in a study of fluent and nonfluent patients and age- and education-matched controls, attributed the increasing semantic blocking effect for the nonfluent patients to overactivation of competitors in the semantically blocked condition and a disruption of a mechanism, localized in left frontal regions, that selects the appropriate lexical representation from competitors. Schnur et al. (2006) attempted to distinguish between the overinhibition (i.e., refractory access) and overactivation accounts of the semantic blocking effect on the basis of patient error patterns. They reasoned that if overinhibition were at work, then omissions should increase but semantically related substitutions should decrease across cycles. Instead, they found that both omissions and semantically related substitutions increased across cycles, which they took to support the overactivation account. It is possible, though, that overinhibition could provide an account of increasing semantic substitution errors. That is, if correct responses, and competitors, are weakly activated due to overinhibition then it could become difficult to select the correct representation from competitors, assuming some type of ratio rule for selection.[2] Thus, the overinhibition account remains a theoretical possibility.

In the Schnur et al. (2006) study, the nonfluent patients with left anterior lesions showed a semantic blocking effect in error rates, which increased linearly across cycles. The linear increase resulted from a combination of decreasing errors in the mixed condition and increasing errors in the blocked condition. In contrast, their fluent aphasic patients did not show a significant semantic blocking effect in error rates. Six fluent aphasic patients obtained a sufficient level of accuracy such that onset latencies could be analysed, and they displayed a semantic blocking effect in onset latencies that was within the range of controls. A study by Schnur, Lee, Coslett, Schwartz, and Thompson-Schill (2005), comparing lesion localization and semantic blocking effects for a subset of the patients from Schnur et al. (2006), found that different regions contributed in qualitatively different ways to the semantic blocking effect. It was found that damage to temporal regions was associated with a greater overall magnitude in the semantic blocking effect, whereas damage to the left inferior frontal gyrus (LIFG) was associated with a greater increase in the semantic blocking effect across cycles. They attributed the greater semantic blocking effect in temporal regions to a disruption of semantic representations or lexical-to-semantic connections whereas the damage to the damage to the LIFG was hypothesized to be specific to a mechanism for selection.

Studies of aphasic patients with damage to the LIFG have begun to converge on the conclusions that the LIFG is involved in an executive selection process. Two recent studies documented cases of patients with damage to the LIFG who had difficulty in overcoming responses that were congruent with the context but incongruent with the task demands (Hamilton & Martin, 2005; Thompson-Schill et al., 2002). Both studies documented that the patients with damage to the

[2] For instance, suppose that in the undamaged system after some time (t), the target response typically has an activation of 150 units whereas the nearest competitor has an activation of 100 units. Due to noise in the system, which has some variance, say 30 units, the activation of the nearest competitor will occasionally be higher than that for the target, resulting in a semantic error. In the damaged system with overinhibition, at time t, activation of the target might typically be 75 units and activation of the competitor 50 units. Assuming that the variance due to noise is at least as great in the damaged system, there will be a greater proportion of trials on which activation for the competitor exceeds that for the target. Whether or not a semantic error or an omission would be predicted would depend on whether one assumed some (high) threshold for production of a response (which should lead to more omissions for the overly inhibited system) or a ratio threshold for response (which would lead to more semantic substitutions).

LIFG had difficulty with incongruent trials on the Stroop task (Stroop, 1935), in which participants must ignore the printed name of a word and instead name the ink colour, and in the recent negatives task, in which participants decided whether a probe item was in an immediately presented list of items, with the critical manipulation being when the current probe item was a member of a previous list. Hamilton and Martin (2005) further showed that the deficit was limited to the verbal domain in the case of patient M.L., as he showed no deficit for tasks involving resolving competition in response to visual stimuli. Although both groups proposed that the LIFG was involved in executive selection, they had different accounts of the nature of the mechanism involved. Thompson-Schill and colleagues have argued that the LIFG is a general selection mechanism involved in different representational levels, including phonological, semantic, and syntactic (Novick, Trueswell, & Thompson-Schill, 2005). They further proposed that the mechanism acts by a top-down change in activation weights based on task demands (Thompson-Schill & Botvinick, 2006). Hamilton and Martin (2005, 2007) instead proposed an executive mechanism, localized in the left IFG, which acts to inhibit verbal representations. Hasher and Zacks (e.g., Hasher & Zacks, 1988; May, Hasher, & Kane, 1999) have long proposed a central role for inhibitory processes in working memory and have argued that these are negatively affected by aging. Given the evidence for a decline in frontal function in aging (Buckner, 2004; Head, Snyder, Girton, Morris, & Buckner, 2005; Pfefferbaum et al., 2000; Schacter, Savage, Alpert, Rauch, & Albert, 1996), it would follow that these mechanisms are likely to have a frontal localization. May et al. (1999) have recently proposed three different aspects to inhibition: an access function that restricts the contents of working memory to only relevant information when irrelevant information is presented simultaneously; a deletion function that removes no longer relevant information; and a restraint function that blocks the production of prepotent responses. The findings from M.L. would implicate impairments in the deletion (for the recent negatives task) and restraint functions (for the Stroop task)—though disruption of these functions appears to be limited to the verbal domain. Although it is possible that these different aspects of inhibition might be dissociable across different patients, such has not yet been established.

In the semantic blocking task, the deletion aspect of inhibition could also play an important role. That is, activated representations from prior naming trials, if they were not suppressed, would interfere with target production, particularly when the prior items were semantically related. Some models of speech production assume that once a word has been produced, the lexical representation for that word is inhibited to prevent its reselection (Dell, 1986; MacKay, 1987). However, according to Dell's (1986) interactive activation model, activation of the suppressed target node will rebound because semantic and phonological neighbours of the target were activated through spreading activation. These would not have been suppressed, and thus their continuing weak activation would serve to converge to reactivate the target. Thus, even for control participants, one might expect some persisting activation of lexical representations from previously produced picture names that would interfere with target selection. That is, if one assumes that target activation must exceed that of competitors by some amount in order for selection to occur, the greater the activation of competitors, the longer the time needed for target activation to exceed this threshold. As items are repeatedly named from the same category, persisting activation from these same-category representations would increasingly impede target selection, both from the persisting activation of the items themselves and from spreading activation from these to related items. If a patient had difficulty with the postselection suppression, even greater interference would be expected.

Dell's (1986) model would predict that the postselection suppression happens at a lexical level of representation during picture naming. Martin and Biegler (2007) argued against such a mechanism operating at the semantic level, as a speaker may need to keep a semantic representation in mind throughout a discourse and refer to related concepts subsequently, whereas allowing a lexical representation that has been activated to remain at a high level of activation would not be helpful, but instead presumably harmful, in producing fluent discourse.

In the present study, we assessed the performance of a patient in our laboratory, M.L., who shows the pattern of preserved word production in isolation but a deficit in production of words in phrasal or sentence context (Freedman et al., 2004; Martin & Freedman, 2001; Martin & He, 2004; Martin, Miller, & Vu, 2004). M.L. shows excellent picture naming, performing at or above the mean for control participants in accuracy on confrontation naming (Martin & He, 2004). In terms of picture-naming latencies for a series of unrelated pictured objects, M.L.'s mean reaction time is about 200 ms longer than the mean for controls, which puts him near the outside edge of their range (Hamilton & Martin, 2005).[3] Previous studies have shown that he is impaired in producing adjective–noun phrases to describe pictures (e.g., "short blonde hair"), producing the required information in piecemeal fashion (e.g., "short . . . short . . . blonde . . . blonde hair"; Martin & Freedman, 2001). He also shows very long onset latencies in describing pictures with sentences that begin with a conjoined noun phrase (e.g., "The cat and the flag move above the tree") compared to matched sentences that begin with a simple noun phrase (e.g., "The cat moves above the flag and the tree"; Martin, Miller, & Vu, 2004). He is also impaired in producing conjoined noun phrases to describe two pictures, showing an exaggerated effect of semantic relatedness (e.g., "jacket and dress") on onset latencies (Freedman et al., 2004). We have attributed these patterns to his difficulty in maintaining several lexical-semantic representations simultaneously during phrasal planning, which is consistent with his deficit in maintaining lexical-semantic information during word list recall (Martin & He, 2004).

The other studies that have assessed deficits in patients' production in context have not typically assessed phrase or sentence production experimentally (though see Schwartz & Hodgson, 2002), and our previous studies of M.L. have not assessed the effects of semantic blocking on picture naming. In the present study we sought to obtain the missing data for M.L., examining the effects of semantic blocking on his picture-naming and word comprehension abilities. To the extent that M.L.'s production deficits are due solely to a short-term memory deficit, we would not predict that he would show any exaggerated effect of semantic blocking on single-picture naming as there is no requirement to maintain more than one representation simultaneously. However, as discussed earlier, evidence from our laboratory has indicated that M.L. has a deficit in inhibiting irrelevant verbal representations, even on tasks that involve only single-word production (Hamilton & Martin, 2005, 2007). We have suggested that this inhibition difficulty may be the source of his short-term memory deficit as Hamilton and Martin's studies demonstrated that he suffers from excessive proactive interference in short-term memory tests. This inhibitory deficit could plausibly give rise to a deficit in lexical selection along the lines suggested by Wilshire and McCarthy (2002) and Schnur et al. (2006). That is, if several semantic representations become highly activated while performing the semantic blocking task, and if inhibition is involved in the executive process that controls lexical selection, then M.L. would be predicted to show an exaggerated effect of semantic blocking. On the other hand, if the semantic blocking effect is due to excessive inhibition of lexical representations, then M.L. would be unlikely to show an exaggerated semantic blocking effect (or may even show a smaller than normal effect) due to his deficit in inhibition. That is, if the semantic blocking effect results from inhibition of lexical

[3] These latencies are for the naming of pictured nouns. For verb naming, M.L. is also highly accurate; however, his latencies are substantially outside the range for controls (Biegler, Martin, & Potts, 2005). As the studies reported here dealt only with noun production and comprehension, this word class difference is not considered further.

representations and the spread of this inhibition to related items, making them difficult to retrieve when they become targets, then M.L.'s inability to suppress verbal representations should mean that he would be better able than controls to retrieve names in the semantically blocked condition.

In the present experiments, both reaction times and error rates were measured in order to determine whether any effect of semantic blocking would show up only in the more sensitive reaction time measure, given M.L.'s highly accurate single-picture naming. We also wished to determine whether any exaggerated semantic blocking effect demonstrated by M.L. would apply only to production or would also be demonstrated in comprehension. As discussed earlier, Martin and Biegler (2007) argued that the executive selection mechanism only affects representations at the lexical level, whereas Thompson-Schill and colleagues (Novick et al., 2005) have argued that similar executive selection processes operate on different levels of linguistic representation and thus would affect tasks not involving lexical selection for production. If the blocking effect arises at the point of selecting a lexical representation for production, one would not expect to find such an effect in comprehension. Wilshire and McCarthy (2002) examined semantic blocking in comprehension for their patient in a picture–word matching task and concluded that the semantic blocking effect was much smaller in comprehension than in production. However, they did note a fairly large semantic blocking effect on the "no" trials, in which the picture and spoken word did not match, which they attributed to the greater semantic similarity of the distractors for the semantically blocked condition. In the present study, we examined whether the blocking effect grew across cycles in two picture–word matching tasks, one involving matching a picture to its name and the other involving matching a picture to an associated word . If the effect does increase across presentation cycles in comprehension as well as in production, then the selection problem would appear to arise at a semantic level rather than at the level or selecting a lexical representation for production.

In addition to M.L., we also tested patients B.Q. and K.V. on this series of tasks. B.Q. is similar to M.L. in several respects, as he is nonfluent in spontaneous speech but shows preserved single-picture naming. He demonstrates a more mixed picture than does M.L. on short-term memory tasks as he has difficulty in retaining both phonological and semantic information, though he is somewhat better than M.L. at maintaining phonological information in short-term memory when no output is required. K.V. has a short-term memory deficit that is slightly less severe than that of M.L. and B.Q. in terms of span, showing some indication of difficulty maintaining phonological information; however he contrasts with both of these patients in that he has fluent speech in conjunction with good picture naming. Both M.L. and B.Q. show deficits in inhibiting irrelevant verbal information whereas K.V. does not.

For both the production and name–picture matching tasks, a single-picture format and a multiple-picture format were used. The single-picture format is like that used in the Schnur et al. (2006) and Wilshire and McCarthy (2002) studies. The multiple-picture format was also employed, as this presentation format has been used in studies by Warrington and colleagues (e.g., Crutch & Warrington, 2003, 2005) of refractory access during comprehension. We included this format because of the possibility that the presence of other pictures might influence the pattern of results. Rate was manipulated in the multiple-pictures format to determine whether we would replicate the rate effects reported in some previous studies. Several weeks intervened between testing on the single-picture and multiple-picture formats for each patient. In the associated word–picture matching task, only the multiple-picture format was used, because of participants' difficulty in deciding on a criterion for judging a match for single-picture presentation.

Patient backgrounds

The performance of the three patients on language, short-term memory, and inhibition tasks is summarized in Table 1. A discussion of performance on these tasks and on others that were difficult to include in tabular format is provided below.

Patient M.L.

M.L. is a right-handed male who was approximately 63 years of age at the time of testing. He sustained a left hemisphere lesion from a cerebral vascular accident (CVA) in 1990. He had two years of college and served as a draftsman prior to his CVA. A recent structural magnetic resonance imaging (MRI) scan obtained from our laboratory revealed a lesion encompassing the left inferior and middle frontal gyri and large lateral areas of the superior and inferior left parietal lobe, though with some sparing of the supramarginal gyrus and angular gyrus. The left temporal lobe is intact. His speech is nonfluent, with a very reduced speech rate, many hesitations, and apparent word-finding difficulties. Based on quantitative production analysis (QPA; Saffran, Berndt, & Schwartz, 1989), he is not impaired on morphological measures, producing a normal rate of function words and inflectional markers. He is impaired on the structural measures, with reduced sentence length and reduced noun phrase and verb phrase complexity. He is not apraxic and shows good single-word repetition with few errors (96%). M.L. demonstrates normal picture-naming and single-word comprehension abilities.

M.L. has a span of about 2.5 words in serial recall. His short-term memory deficit primarily

Table 1. *Patient background information*

		M.L.	*B.Q.*	*K.V.*	*Controls*	*Range*
Single-word production	PNT (accuracy in %)	98	93	96	96	
Single-word comprehension	PPVT (standardized score)	117	99	83	100[c]	
Short-term memory	Serial recall word span	2.5	2.0	3.5		
	Category-probe word span	1.8	80[a]	3.6	5.4	3.4 to 7.0
	Rhyme-probe word span	3.0	74[a]	5.6	7.0	5.8 to 9.0
Semantic attribute judgements	Two-item (accuracy in %)	65 (100)[b]	74	98		
	One-item (accuracy in %)	88	81			
Stroop (RT in ms)	Neutral	2,470	NA	1,014	777	
	Congruent	1,889	NA	990	828	
	Incongruent	3,449	NA	1,549	974	
	Interference (incong−neut)	979	NA	535	197	101 to 279
Antisaccade (accuracy in %)	Prosaccade	93	68	93	97	93 to 100
	Antisaccade	80	41	58	72	59 to 94
Recent negatives (RT in ms)	Recent negative RT	2,905	2,154	NA	1,006	
	Nonrecent negative RT	2,174	1,779	NA	915	
	Interference (RN−NRN)	731	375	285	91	−74 to 337
	Recent negative % correct	63	56	93	95	
	Nonrecent negative % correct	88	85	95	99	
Picture−word interference (RT in ms)	0-ms SOA					
	Related	1,453	5,456	1,049	876	
	Unrelated	1,224	4,402	1,049	835	
	Difference (rel−unrel)	229	1,054	0	41	−40 to 87
	300-ms SOA					
	Related	1,814	NA	1,074	830	
	Unrelated	1,074	NA	950	801	
	Difference (rel−unrel)	740	NA	124	29	−70 to 124

Note: PNT = Philadelphia Naming Task. PPVT = Peabody Picture Vocabulary Test. incong = incongruent. neut = neutral. RN = recent negative. NRN = nonrecent negative. SOA = stimulus onset asynchrony. rel = related. unrel = unrelated.
[a]In percentages. See Footnote 3. [b]Score in parentheses is with visual presentation, which should minimize load. [c]*SD* = 15.

involves a difficulty in retaining lexical-semantic information (Martin & He, 2004). For instance, M.L. does not show the typical advantage for recall of word lists over nonword lists, scoring 40% correct for word lists and 35% correct for nonword lists when averaging across two- and three-item lists. His difficulty in maintaining lexical- semantic information is also evident on tasks requiring no verbal output. On a category-probe task, in which participants judge whether a probe item is in the same category as any list item, M.L. obtained a span of only 1.8 items. However, M.L. showed better performance (i.e., a span of 3.0 items) on a rhyme probe task, in which participants judge whether a probe rhymes with any list word, demonstrating a better ability to retain phonological information. M.L. also showed an impaired ability to make semantic judgements about attributes when these judgements placed a load on short-term memory. That is, when asked to decide which of two objects possessed a particular attribute (e.g., "Which is rough, cotton or sandpaper?"), he scored only 65% correct. However, he obtained 88% correct for shortened questions containing only one object (e.g., "Is cotton rough?") and scored 100% correct for the original attribute questions with two nouns when these were presented visually for an unlimited amount of time—that is, minimizing memory load.

Recently, Hamilton and Martin (2005, 2007) demonstrated that M.L. had difficulty on tasks involving the inhibition of irrelevant verbal information, and they suggested that M.L.'s short-term memory deficit might derive from this inhibition deficit. Hamilton and Martin (2005) examined M.L.'s performance on a "recent negatives" short-term recognition probe task in which participants judge whether a probe item matches an item in the current list. Healthy participants take longer to reject a probe that matches an item from one list back (i.e., a recent negative) than a probe that matches an item several lists back. M.L. showed greatly exaggerated difficulty in rejecting the recent negatives, in one administration accepting 38% of the recent negatives as appearing in the current list. In addition, M.L. showed similarly exaggerated interference in rejecting probes that were semantically or phonologically related to items in the current or preceding list (Hamilton & Martin, 2007). Thus, Hamilton and Martin argued that M.L. had difficulty inhibiting verbal information that was no longer relevant (i.e., in the deletion function as proposed by May et al., 1999).

Hamilton and Martin (2005) also reported that M.L. displayed an exaggerated interference effect in the standard Stroop colour word task (Stroop, 1935). He also shows exaggerated semantic interference on picture–word interference task (Biegler, 2006)—that is, in naming pictures in the presence of a semantically related distractor words (e.g., Schriefers, Meyer, & Levelt, 1990). To the extent that both tasks require the ability to inhibit a prepotent response (e.g., reading a written word), Hamilton and Martin (2005) proposed that M.L.'s impaired performance was due to a damaged executive inhibitory mechanism, conceptually similar to the restraint mechanism proposed by May et al. (1999) and identified by Miyake et al. (2000) in their factor analytic study of the components of executive function. Importantly, his deficit on these two tasks occurred even though the tasks placed no demand on short-term memory. In contrast to his deficits on these verbal tasks, M.L. performed within the range of controls in tasks requiring an inhibitory response with nonverbal stimuli—that is, on an anti saccade task and spatial version of the Stroop task. Based on M.L.'s pattern of performance in verbal and nonverbal inhibitory tasks, Hamilton and Martin (2005) attributed M.L.'s deficits to impaired inhibitory mechanisms, which act to suppress irrelevant verbal representations. In terms of May et al.'s analysis, he would have deficits in both the deletion and restraint aspects of inhibition.

Based on M.L.'s performance on Stroop and picture–word interference tasks, we would argue that his verbal inhibition deficit affects at least a lexical level of representation, as interference in these paradigms has been attributed to competing activation at a lexical rather than a conceptual level (Schriefers, Meyer, & Levelt, 1990). The data from the recent negatives task would suggest that the inhibition deficit also exists at semantic and phonological levels. However, if one assumes an interactive activation network that is connected to working-memory representations (e.g., Martin, Lesch, & Bartha, 1999), then a failure to inhibit at the lexical level will lead to persisting activation at the semantic and phonological levels due to spreading activation.

Patient B.Q.

B.Q. is a right-handed male who was approximately 70 years of age at the time of testing. He sustained a left hemisphere lesion from a CVA in 1999. He had a college education and worked as an engineer prior to his CVA. A structural MRI scan revealed a substantial lesion including the left frontal, parietal, and temporal regions. B.Q. is a nonfluent speaker, showing severely reduced speech rate, hesitations, and word-finding difficulties. On the QPA (Saffran et al., 1989), he is impaired on both the structural and morphological measures. B.Q. shows relatively good picture naming, word repetition, and word comprehension, being within or just outside the range of controls in terms of accuracy on tasks with single items.

B.Q. displays a restricted short-term memory capacity, with a span of two words. Unlike M.L., he does not show a clear dissociation between semantic and phonological short-term memory, as he shows a mixed pattern across tasks. Although B.Q. shows phonological effects in word list recall (for example, showing a substantial word length effect), his nonword repetition is very poor and much worse than his word repetition, which suggests difficulty in retaining phonological information. However, on the category and rhyme probe tasks discussed previously for M.L., B.Q. did slightly better on the category (80% correct) than on the rhyme probe task (74% correct) when averaging across one- to four-item lists, though performance on both tasks was well below the range of controls.[4] On the two-item attribute judgement task described for M.L., B.Q. scored 74% correct. Unlike M.L., B.Q.'s performance improved only modestly on the one-item version (81% correct).

Similar to M.L., B.Q. shows evidence of difficulty inhibiting irrelevant verbal information. Due to a colour-naming deficit, B.Q. is unable to perform the standard Stroop task. On a picture–word interference task, B.Q. showed an exaggerated interference effect of 1,054 ms to name pictures in the presence of semantically related distractors, a difference that was far outside the range of controls (−40 to 87 ms). In addition, on an auditory version of the recent negatives task, B.Q. displayed an exaggerated interference effect, as he was significantly less accurate on rejecting a probe that had appeared in the immediately preceding list than on a probe that had appeared several lists back.

Patient K.V.

K.V. is a right-handed male who was approximately 72 years of age at the time of testing. He suffered from an extracranial cerebral vascular incident due to arterial blockage in 2003. He had a high-school education and was previously employed in the military and as a car salesman. As we have been unable to obtain a structural MRI for K.V. due to a medical condition, the locus of his lesion is unknown. (A computed tomography, CT, scan at the time of his stroke revealed no abnormalities.) K.V. displays excellent picture naming, but his single-word comprehension is considerably below that of M.L. and B.Q.

K.V. has a word span of about four items, larger than that of M.L. or B.Q., though he is still impaired relative to controls. His nonword span is substantially less than his word span, as he scored only 20% correct on two-item, one-syllable nonword lists and only 70% correct on repeating single one-syllable nonwords. However, K.V. did

[4] It was difficult to calculate a span measure on these probe tasks for B.Q. as had been done previously with other patients (e. g., Martin & He, 2004), as his performance fluctuated across list lengths rather than decreasing systematically.

quite well on both the rhyme probe task and category probe tasks, scoring close to the lower end of the range for controls on both, suggesting a relatively preserved ability to retain both semantic and input phonological information. Further evidence of his preserved semantic retention comes from the two-item attribute judgement task, where K.V. scored 98% correct (e.g., "Which is rough, sandpaper or cotton?"), performing considerably better than M.L. and B.Q. K.V. scored 97% correct in a single-word repetition task. Like B.Q., K.V. thus shows evidence of difficulty in retaining output phonological representations with good retention of input phonological representations (Martin et al., 1999). Unlike B.Q., however, K.V. shows consistent evidence of good retention of semantic information (despite showing worse performance than M.L. or B.Q. on a vocabulary measure (Peabody Picture Vocabulary Test; Dunn & Dunn, 1981).

On the recent negatives task, K.V. performed within the range of controls (unpublished data). For probes that were semantically or phonologically related to items in the same or previous list, K.V. displayed nonsignificant facilitation, rather than exaggerated interference. Although K.V. shows an exaggerated Stroop effect, he showed a picture–word interference effect within the range of controls at both stimulus onset asynchronies (SOAs) that were tested (see Table 1).[5] Thus, aside from the Stroop effect, K.V. does not display excessive proactive interference in the previously discussed short-term memory tasks or exaggerated inhibition difficulties in the picture–word interference task. Thus, to the extent that exaggerated semantic blocking effects derive from a deficit in inhibition, K.V. was hypothesized to perform close to or within the range of controls in the following experiments.

EXPERIMENT 1A: SEMANTICALLY BLOCKED NAMING WITH SINGLE PICTURES

The purpose of Experiment 1A was to first assess whether M.L. would show an exaggerated semantic blocking effect in production, as has been reported for some other nonfluent patients with frontal damage (McCarthy & Kartsounis, 2000; Schwartz & Hodgson, 2002; Wilshire & McCarthy, 2002). If M.L. did, in fact, show an exaggerated semantic blocking effect, this would provide evidence that the semantic blocking effect arises due to the overactivation of verbal representations, given his deficit in inhibiting irrelevant verbal representations. A similar prediction would be made for B.Q. In contrast, no excessive blocking effect was anticipated for K.V., given his generally normal performance on the inhibition tasks. This experiment used the materials and procedures (with minor modifications) from the Schnur et al. (2006) study, with participants naming single pictures that were presented cyclically in semantically blocked or mixed conditions.

Method

Participants

A total of 7 control participants with no history of neurological injury and patients M.L., B.Q., and K.V. participated in the semantically blocked naming task. Testing on this experiment, and all the experiments reported here, was carried out between 2005 and 2007. Thus, all of the patients were at least two years poststroke at the time of testing. Both the control participants and patients received $10 per hour of participation. The control participants were education- and age-matched with the patients, with ages ranging

[5] The discrepancy in performance between the Stroop and picture–word interference paradigms is puzzling, especially since he obtained very few errors in both tasks (3/70 for Stroop and 4/60 for picture–word interference). However, recent unpublished verbal Stroop data obtained in our laboratory have also shown large interference effects in reaction times for patients who are more similar to K.V. than M.L. with regard to speech fluency, short-term memory, and language processing in a semantic context (Crowther, 2006). Conceivably, the verbal Stroop task could be especially difficult for a wide range of aphasic patients and not restricted to patients with large left frontal lesions.

from 55–75 years and an education level of at least a high-school degree, with most having had some college education. English was the first language of all participants.

Materials and design

The stimuli used in Experiment 1A were the same materials as those used by Schnur et al. (2006); see Appendix A. The materials consisted of 72 Snodgrass and Vanderwart (1980) pictures or other similar line drawings selected from 12 different categories. Each category contained six exemplars, which were presented in both semantically blocked (e.g., ear, arm, toe, nose, chin, thumb) and mixed sets (e.g., ear, table, goat, fan, mountain, dress). The materials were matched on frequency, phonological onset, and rhyme similarity for both semantically blocked and mixed sets (see Schnur et al. for more detailed methods). The semantically blocked and mixed sets each contained six pictures. Both set types were presented across four cycles with the pictures appearing in random order during each cycle. Following the sixth picture, the next cycle began repeating the previous set of pictures (in a different order). One block consisted of four cycles with six pictures per cycle, totalling 24 pictures presented in each block. There were 24 blocks total: 12 same-category blocks and 12 mixed blocks. The same-category and mixed blocks were presented in a different random order for each participant.

Procedure

All pictures were presented using Psyscope 1.2.5 (Cohen, MacWhinney, Flatt, & Provost, 1993). Before the experiment began, participants participated in a practice session in which they were familiarized with each of the 72 pictures presented during the experiment. A single picture appeared on the screen; 1,000 ms after picture onset, the correct name appeared. Participants were instructed to name the picture using the word printed on the screen and to proceed to the next picture at their own pace by pressing the space bar.

Each trial began with the simultaneous presentation of a beep and a single picture that remained on the screen for 2,000 ms. Two small dots at the bottom of the screen indicated when the voice key was triggered. Following the participants' response, the experimenter pressed the keys 1, 2, or 3, indicating whether the response was correct, an equipment error occurred, or a response error occurred, and proceeded to the next trial. The experimenter took approximately 900 ms to classify the response.

Data analysis

Reaction times were removed if they were classified as an error response or were three standard deviations above or below each participant's mean (2.5 *SD*s for controls). Errors were categorized into two types: equipment errors in which the voice key was incorrectly triggered or response errors in which the incorrect name was produced for a picture. Data analyses were carried out using log transforms for two reasons. First, reaction times tend to be skewed, and this was particularly the case for the patients. A log transformation thus changes the distributions to be closer to normal. Also, many studies have shown that the size of effects tends to increase as reaction time increases. Thus, looking at effects in terms of the proportions instead of differences is often recommended when comparing effects across individuals with different mean reaction times. Transforming the data to log transforms has essentially the effect of changing effects into proportions (see Verhaeghen & De Meersman, 1998). As reaction times for patients were highly skewed, we conducted the following analyses for patients and control participants using a natural log transformation, in order to compare the performance of the patients to that of the controls. The data for the patients were analysed individually using items as a random factor, while control results were analysed both by items and by subjects. A 2 (blocking) $\times$ 4 (cycle) repeated measures analysis of variance (ANOVA) was performed for both the subject and item analyses for patients and controls. In addition to analysing the main effect of cycle and its interaction with blocking, we also assessed whether there was a linear effect of cycle and whether the blocking effect increased linearly with cycle. A linearly increasing blocking effect with cycle was previously reported by Schnur et al. (2006) for their control participants. If the Blocking × Cycle interaction was significant, linear contrast analyses were also performed on the blocked and mixed conditions separately, in order to assess whether the patients showed slowing with repeated retrieval of items in the blocked condition.

Results

See Table 2 for the ANOVA results and Table 3 for condition means. In this and the subsequent experiments, effects that are discussed were significant at the $p < .05$ level in both the subjects (F_1) and items (F_2) analyses for controls and in the item (F_2) analyses for patients, unless otherwise noted. Effects that were significant are set in bold in the tables, but in the case of controls only if the effect was significant in both subject and items analyses.

Controls

Only 0.3% equipment and 1.0% response errors were found for controls. Excluded onset latencies that fell 2.5 standard deviations above or below the mean constituted 1.4% of the data.

Controls showed significantly decreasing reaction times with cycle in both conditions; however, the decrease was greater in the mixed condition. They failed to show a main effect of blocking, but showed an interaction of blocking with cycle. The linear component of this interaction was significant. The controls obtained a significant facilitation effect (27 ms) during Cycle 1, $t_1(6) = 2.46$, $p = .049$; $t_2(71) = 3.47$, $p = .001$, which switched to interference that progressively increased across cycles (see Table 3).

M.L.

M.L. made few errors with only 1.2% response errors and 3.8% equipment errors. Due to his low error rate, M.L.'s errors were not analysed further. A further 2.4% of the data, which were more than 3 standard deviations away from the mean, were removed from the analysis.

M.L. was slower to name items in the semantically blocked condition (1,215 ms) than in the mixed condition (961 ms). The blocking effect for M.L. increased linearly from 60 ms at Cycle 1 to 437 ms at Cycle 4, with reaction times increasing in the blocked condition but decreasing in the mixed condition. The effect at Cycle 4 was up to 10 times greater than the largest difference for controls in terms of nontransformed reaction times. When comparing natural log transformed scores, M.L. obtained a semantic blocking effect that was over three times greater than the largest difference for controls.

Table 2. *ANOVA results (including contrasts) for natural log transformed data by subject* (F_1) *and by items* (F_2) *as a random factor in Experiment 1A*

	Controls						*M.L.*			*B.Q.*			*K.V.*		
	df			*df*			*df*			*df*			*df*		
	Num	*Den*	F_1	*Num*	*Den*	F_2	*Num*	*Den*	F_2	*Num*	*Den*	F_2	*Num*	*Den*	F_2
Blocking	1	6	5.54	1	71	2.75	***1***	***65***	***15.28******	***1***	***59***	***97.50******	***1***	***63***	***274.37******
Cycle	***3***	***18***	***26.48******	***3***	***213***	***141.77******	3	195	1.82	***3***	***177***	***24.30******	***3***	***189***	***450.12******
Linear	***1***	***6***	***24.26*****	***1***	***71***	***230.17******	1	65	2.00	***1***	***59***	***19.92******	***1***	***63***	***662.86******
Blocking × Cycle	***3***	***18***	***11.44******	***3***	***213***	***19.26******	***3***	***195***	***2.97****	***3***	***177***	***49.05******	***3***	***189***	***46.27******
Blocking × Linear	***1***	***6***	***14.172*****	***1***	***71***	***40.46******	***1***	***65***	***6.25****	***1***	***59***	***60.87******	***1***	***63***	***52.65******

Note: ANOVA = analysis of variance. Num = numerator. Den = Denominator. Effects that were significant are set in bold italic, but in the case of controls only if the effect was significant in both subject and items analyses.
$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

Table 3. *Semantically blocked single-picture naming, Experiment 1A*

		Cycle			
		1	*2*	*3*	*4*
Controls	Blocked	720	673	666	673
	Mixed	747	665	651	644
	Difference	− 27	8	15	29
	Range	− 64 to 6	− 1 to 26	− 1 to 30	− 9 to 50
	Difference (nat log)	− .033	.011	.024	.046
	Range	.007 to .01	.002 to .038	− .004 to .049	.011 to .084
M.L.	Blocked	1,124	1,117	1,286	1,331
	Mixed	1,064	952	932	894
	Difference	60	165	354	437
	Difference (nat log)	.005	.100	.254	.204
B.Q.	Blocked	2,445	2,978	3,741	2,869
	Mixed	2,960	2,292	2,210	1,799
	Difference	− 515	686	1,531	1,070
	Difference (nat log)	− .074	.118	.307	.359
K.V.	Blocked	876	749	761	743
	Mixed	837	736	691	693
	Difference	39	13	70	50
	Difference (nat log)	.038	.015	.092	.070

Note: Onset latencies in ms.

B.Q.

B.Q. made few errors with only 6.8% response errors and 2.9% equipment errors. Due to his low error rate, B.Q.'s errors were not analysed further. A total of 2.4% of the data were removed as outliers.

B.Q. was slower to name items in the semantically blocked condition (3,008 ms) than in the mixed condition (2,315 ms). He showed a dramatic linear increase in the blocking effect across cycles, going from a nonsignificant 515 ms facilitation effect at Cycle 1 ($t < 1$) to 1,070 ms of interference at Cycle 4. His blocking effect at Cycle 4 was almost 30 times greater than the largest difference for controls in terms of nontransformed scores. As shown in Table 3, the increasing blocking effect was due to both progressively increasing reaction times in the blocked condition and decreasing reaction times in the mixed condition. When comparing the semantic blocking effect in terms of natural log transformed scores, B.Q. displayed a difference that was more than four times greater than the largest difference for controls.

K.V.

K.V. obtained 3.1% response errors and 2.1% equipment errors. Since K.V. had such few errors, they were not analysed further. A total of 3.1% of the data for him were removed as outliers.

K.V. was slower to name items in the semantically blocked condition (782 ms) than in the mixed condition (739 ms). He displayed effects across all four cycles that were either within or just outside of the range of controls. In contrast to M.L. and B.Q., the semantic blocking effect was not due to continually increasing reaction times in the semantic blocked condition, but instead was attributable to reaction times that decreased at a faster rate in the mixed condition than in the semantically blocked condition.

EXPERIMENT 1B: SEMANTICALLY BLOCKED PICTURE NAMING WITH PICTURE ARRAYS

This experiment was similar to Experiment 1A, but with multiple pictures presented on each trial. The studies reviewed in the Introduction differed in whether single or multiple pictures were presented, which may be a factor affecting the semantic blocking effect. Presentation rate was also manipulated, as some aphasic patients have been found to show an increased blocking effect at faster presentation rates (McCarthy & Kartsounis, 2000; Wilshire & McCarthy, 2002).

Method

Participants

The participants were M.L., B.Q., and K.V. as well as 9 older controls recruited from the same subject pool as that in Experiment 1A (age: 58–79 years old). Patients were given $12/hour in compensation for participation, and older controls were given $10/hour.

Materials and procedure

The pictures were 72 pictures, 6 each from 12 semantic categories (see Appendix B). The pictures were taken from the International Picture-Naming Project pictures set (Szekely et al., 2004), which includes materials drawn from several different sources.

At least two months separated participation in Experiments 1A and 1B. Participants were presented with an array of six pictures, either drawn from the same semantic category or each drawn from different semantic categories. Blocks of semantically blocked and mixed items were alternated in an ABBAABBAABBA design. All participants performed the experiment in the same order. Items were probed at either a short (1-s) or long (4-s) response–stimulus interval (RSI). Participants completed the experiment in two sessions. In the first session, the long RSI preceded the short RSI, and in the second session the reverse was the case. Participants also completed Experiment 2B (see below) during the same sessions. In Session 1, they did comprehension first (2B) followed by production (1B), and in the second session, they did the reverse. Given the extended length of the experimental sessions for Experiment 1B and because of the high name agreement for the pictures in 1B based on standardized norms (mean = 88%), we decided to shorten testing time by not including a familiarization phase.

In a single trial, participants were presented with an array of six pictures. At the beginning of a trial, an electronic beep sounded, and one picture was visually highlighted by the appearance of a border around that picture. Once the participant had produced the name of that picture, the experimenter pressed a key to indicate an equipment error, response error, or correct response. Voice-key errors were monitored by the experimenter by means of a small cross that appeared in the top left-hand corner of the screen indicating when the voice-key had been activated. Once the experimenter pressed the key (which took approximately 900 ms after the participant's response), there was a 1,000-ms or 4,000-ms pause (depending on rate condition), and then the next trial would commence. Participants were given up to one minute to respond (this cut-off was only relevant for B.Q., who would occasionally take a very long time to produce a response; no other participant had any onset latencies over 8 s). Within a block, each picture was probed four times for a total of 24 trials. In a pilot study, it was found that if items were presented in cycles in which all six pictures were probed before repeating any picture, participants would predict the last item in each cycle. Thus, items were not presented in cycles but instead in a different semirandom order for each block with the constraint that no item could be repeated twice in a row. Thus, rather than cycle being a factor in this experiment, the corresponding factor was presentation number (referred to as the presentation factor in the analyses below). Each participant received the same random order for every item in a block.

Data analysis

Equipment and naming errors were removed from the analysis. Outliers were classified as being values greater than 3 standard deviations from the mean for all participants and were removed from the analysis. Even though the amount of data excluded as errors or outliers was very low, a large number of data points would have been

Table 4. *ANOVA results (including contrasts) for natural log transformed data by subject* (F_1) *and by items* (F_2) *as a random factor, Experiment 1B*

	Controls						*M.L.*			*B.Q.*			*K.V.*		
	df			*df*			*df*			*df*			*df*		
	Num	*Den*	F_1	*Num*	*Den*	F_2	*Num*	*Den*	F_2	*Num*	*Den*	F_2	*Num*	*Den*	F_2
Blocking	***1***	***8***	***47.89******	***1***	***71***	***56.72******	***1***	***71***	***81.88******	***1***	***71***	***14.59******	***1***	***71***	***7.86*****
Presentation	3	24	2.38	3	213	7.05***	3	213	1.67	3	213	0.64	***3***	***213***	***6.78******
Linear	—	—	—	1	71	5.70*	—	—	—	—	—	—	***1***	***71***	***11.93*****
Rate	***1***	***8***	***9.03****	***1***	***71***	***227.26******	***1***	***71***	***15.73******	***1***	***71***	***12.29*****	***1***	***71***	***6.85****
Blocking × Presentation	3	24	1.96	3	213	2.34	***3***	***213***	***10.49******	***3***	***213***	***3.47****	3	213	0.87
Blocking × Linear	—	—	—	—	—	—	***1***	***71***	***31.72******	***1***	***71***	***4.7****	—	—	—
Blocking × Rate	***1***	***8***	***16.95*****	***1***	***71***	***10.31*****	1	71	1.49	1	71	0.18	1	71	0.42
Presentation × Rate	3	24	1.62	3	213	0.96	3	213	1.29	3	213	2.20	3	213	0.99
Blocking × Presentation × Rate	3	24	0.50	3	213	0.44	3	213	0.41	3	213	0.64	3	213	0.63

Note: ANOVA = analysis of variance. Num = numerator. Den = Denominator. Effects that were significant are set in bold italic, but in the case of controls only if the effect was significant in both subject and items analyses.
$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

excluded from the item analysis for each patient, as excluding a single observation for any item would result in all observations for that item being discarded from the repeated measures ANOVA. Thus, for the purpose of this analysis, missing data points were estimated by using the item and condition mean—that is, missing value for item i in condition j = mean(item i) + mean (condition j) − grand mean.[6] All other analyses were the same as those in Experiment 1A, with the addition of the rate factor to the overall ANOVA.

Results

See Tables 4, 5A, and 5B for the ANOVA results and the condition means.

Controls

Control participants obtained 0.8% response errors and 1.3% equipment errors. A further 1.4% of the data were removed, which were more than 3 standard deviations from each participant's mean for the different conditions.

Control participants were significantly slower to name items in the semantically blocked condition (958 ms) than in the mixed condition (903 ms). They showed faster naming latencies in the short RSI condition (898 ms) than in the long RSI condition (1,002 ms). Controls also showed a significant Blocking × RSI interaction, with the blocking effect being larger at the short RSI (34 ms) than at the long RSI (70 ms).

M.L.

M.L. obtained 1.9% response errors and 3.5% equipment errors. A further 2.7% of the data were removed for him, which was more the 3 standard deviations outside of each condition mean.

[6] An independent measures ANOVA was also run without replacement values, and similar results were found in the analysis.

Table 5A. *Semantically blocked picture array naming for short RSI, Experiment 1B*

		Presentation			
		1	*2*	*3*	*4*
Controls	Blocked	917	922	918	901
	Mixed	901	894	876	851
	Difference	16	28	42	50
	Range	−22 to 75	54 to 161	−30 to 239	16 to 283
	Difference (nat log)	.026	.028	.034	.041
	Range	−.072 to .154	−.037 to .083	−.033 to .137	.001 to .104
M.L.	Blocked	1,330	1,316	1,345	1,432
	Mixed	1,241	1,218	1,116	1,060
	Difference	89	98	229	372
	Difference (nat log)	.015	.129	.087	.190
B.Q.	Blocked	3,290	4,646	4,540	5,169
	Mixed	3,078	3,278	4,183	3,126
	Difference	212	1,368	357	2,043
	Difference (nat log)	.011	.235	.077	.287
K.V.	Blocked	1,040	968	988	915
	Mixed	961	937	913	815
	Difference	79	31	75	100
	Difference (nat log)	.047	.039	.059	.090

Note: Onset latencies in ms. RSI = response−stimulus interval.

Table 5B. *Semantically blocked picture array naming for long RSI, Experiment 1B*

		Presentation			
		1	*2*	*3*	*4*
Controls	Blocked	991	1,024	992	1,000
	Mixed	949	931	918	904
	Difference	42	93	74	96
	Range	−59 to 119	−18 to 72	−26 to 155	−16 to 145
	Difference (nat log)	.035	.067	.071	.086
	Range	−.013 to .099	.005 to .110	−.021 to .196	.012 to .182
M.L.	Blocked	1,235	1,209	1,372	1,361
	Mixed	1,166	1,040	1,008	995
	Difference	69	169	364	366
	Difference (nat log)	.042	.110	.236	.312
B.Q.	Blocked	3,962	4,083	3,342	3,952
	Mixed	3,184	2,472	2,712	2,890
	Difference	778	1,611	630	1,062
	Difference (nat log)	.051	.268	.175	.198
K.V.	Blocked	1,000	1,000	1,029	970
	Mixed	1,023	943	924	913
	Difference	−23	57	105	57
	Difference (nat log)	.004	.054	.089	.045

Note: Onset latencies in ms. RSI = response−stimulus interval.

M.L. was slower to name items in the semantically blocked condition (1,325 ms) than the mixed condition (1,159 ms) and at the short RSI (1,257 ms) than at the long RSI (1,173 ms), in contrast to the controls who were faster to name items at the short RSI. M.L. showed no main effect of presentation, but the blocking effect did increase linearly across presentations, from 79 ms at Presentation 1 to 369 ms at Presentation 4. The blocking effect at Presentation 4 was almost twice as great as the largest difference for controls in both raw and natural log transformed scores.

B.Q.

B.Q. made 7.1% response errors. Due to a large number of equipment errors, his onset latencies were measured from a digitized recording of the session instead of a voice-key. A total of 2.8% of the data were removed as outliers.

B.Q. was slower to name items in the semantically blocked condition (4,123 ms) than in the mixed condition (3,115 ms) and at the short RSI (3,914 ms) than at the long RSI (3,325 ms), showing an effect of RSI like M.L. but opposite to that of the controls. B.Q. failed to show a significant effect of presentation, but the blocking effect did increase linearly across presentations, from 495 ms at Presentation 1 to 1,553 ms at Presentation 4. The blocking effect for him was over 7 times greater than the largest difference for controls in terms of nontransformed scores and, in terms of log transformed scores, was almost twice as great as the largest difference for controls.

K.V.

K.V. made only 0.4% response errors and 0.4% equipment errors. A total of 1.5% of the data were removed as outliers for him.

K.V. was slower to name items in the semantically blocked condition (989 ms) than in the mixed condition (929 ms) and at the long RSI (975 ms) than at the short RSI (942 ms), showing an effect of RSI similar to that for the control participants. K.V. also had a significant main effect of presentation, which included a significant linear effect of decreasing onset latencies across presentations. The size of the blocking effect for K.V. was within the range of controls for all presentations at both RSIs.

Discussion: Experiment 1

The results for the older control participants in Experiment 1A (with single-picture presentation) replicated those obtained by Schnur et al. (2006), as the controls demonstrated a semantic blocking effect that increased linearly with cycle. Somewhat different results were found for control participants in Experiment 1B, which employed a multiple-picture display. The size of the semantic blocking effect at the final presentation was smaller than that in Experiment 1A (29 ms vs. 50 ms), and, in fact, the interaction of Blocking × Presentation was far from significant.

With regard to the rate manipulation in Experiment 1B, we obtained results that were similar to those reported in other studies with nonfluent patients (McCarthy & Kartsounis, 2000; Schwartz & Hodgson, 2002). That is, both of the nonfluent patients had more difficulty when items were presented at a faster rate (overall, M.L. being 84 ms slower and B.Q. 589 ms slower), whereas the control participants and K.V. were actually faster to respond when items were presented at a faster rate (controls 66 ms faster and K.V. 33 ms faster). We hypothesize that the slower rates resulted in longer times for the controls and K.V. because the task was quite easy for them, and hence they tended to lose the focus of attention with the longer delay between response and subsequent stimulus. We did not, however, replicate McCarthy and Kartsounis's finding of a greater effect of semantic blocking at the faster rate for either M.L. or B.Q., as shown by the lack of a significant Blocking × Rate interaction for either patient.

The semantic blocking effects in reaction times for M.L. and B.Q. in Experiments 1A and 1B were analogous to the semantic blocking effects in error rates reported by Schnur et al. (2006) for nonfluent aphasic patients with left anterior lesions, thus providing a replication of their findings for nonfluent patients. That is, M.L. and B.Q.

showed greatly exaggerated semantic blocking effects in Experiments 1A and 1B. M.L. showed a regularly increasing effect across cycles that was substantially outside of the range of controls. B.Q.'s pattern was noisier, particularly in Experiment 1B, though he also showed a significant linear trend in the increase in the blocking effect and effects that were substantially outside of the range for controls. In contrast, K.V. performed more similarly to controls. K.V. displayed a repetition priming effect in both conditions, which was reduced for the semantically blocked condition. Furthermore, his semantic blocking effect at each cycle was close to or within the range of controls.

As discussed earlier, longer reaction times for semantically blocked than for mixed conditions could be attributed to spreading inhibition of related lexical representations that is sustained over cycles. Accordingly, an exaggerated semantic blocking effect for patients could arise from overly suppressed lexical representations. However, this view is not consistent with the deficits in inhibiting irrelevant verbal information that has been demonstrated for M.L. (Hamilton & Martin, 2005, 2007), based on his exaggerated difficulty in the Stroop task and his greater susceptibility to proactive interference from recently presented items. We propose instead that the pattern of performance observed for control participants and patients is consistent with an overactivation account, and that a more parsimonious explanation for the exaggerated semantic blocking effects observed for patients M.L. (and potentially for B.Q.) would presume a deficit in a postselection inhibition mechanism outside of the lexicon (Martin & Biegler, 2007).[7] In line with several models of word production (Dell, 1986; MacKay, 1987), we assume that once an item has been produced, its lexical representation is inhibited to prevent reselection. In order to account for the semantic blocking effect, we have to assume that either this inhibition is incomplete or that the suppressed item rebounds to an above-baseline level, due to spreading activation from still-activated neighbours. Thus, previously produced items will remain somewhat activated, increasing the competition from these items during the production of semantically related targets. For M.L. and B.Q., we assume a deficit in this postselection mechanism, such that just-produced items remain highly activated, with this activation increasing over repeated cycles more than for controls. That is, if a competitor is highly activated, then a target will have to become highly activated in order for its activation to exceed that of competitors. If this highly activated target is not suppressed following production, it will become an even greater competitor for the next target. Thus, for them, the semantic blocking effect increases disproportionately across presentations as activation accrues with repeated sampling from the same category.

Schnur et al. (2006) found that fluency was significantly correlated with the semantic blocking effect such that the more nonfluent the patient, the greater the blocking effect. Other patient characteristics, including lexical access abilities, conceptual processing, or semantic comprehension, did not correlate significantly with the semantic blocking effect. Furthermore, the analysis of fluent patients' reaction times revealed a semantic blocking effect that was within the range of controls. The performance observed for M.L., B.Q., and K.V. is consistent with their findings as the nonfluent patients, M.L. and B.Q., showed an excessive semantic blocking effect, while the effect for K.V., a fluent patient, was near the range of controls. In line with the proposal of Wilshire and McCarthy

[7] Given that some production models assume that lateral inhibition is involved in lexical selection (e.g., Stemberger, 1985), one might hypothesize that M.L. has a deficit in lateral inhibition (rather than postselection inhibition) that results in overactivation. However, a deficit in lateral inhibition could not account for M.L.'s poor performance on the recent negatives task. Moreover, the predictions of a deficit in lateral inhibition are not straightforward. Presumably, lateral inhibition for patients like M.L. would work in the same manner as that for controls, but only more slowly, such that more time would be needed until a critical difference between the target and its competitors was achieved. The carryover effect of activation from previously named items from the same category would depend on the state of the target and its competitors once the selection criterion for the target was reached. If patients used the same criterion, then no difference from controls would be expected in terms of the carryover across cycles.

(2002), one might therefore hypothesize that the increased semantic blocking effect and the non-fluency of the patients' spontaneous speech derive from the same source. That is, these patients have difficulty selecting from highly activated lexical representations. Wilshire and McCarthy (and Schnur et al.) attributed this deficiency to a disruption of a mechanism for selection. Another somewhat different hypothesis, suggested above, is that the selection mechanism is one that inhibits lexical representations after production.

Both proposals assume that the difficulty is at the stage of selecting from highly activated lexical representations. However, it is possible that the deficit might instead be at the semantic level, as proposed by Thompson-Schill and colleagues (Kan & Thompson-Schill, 2004). That is, selection of a semantic representation from a picture might be compromised when several similar representations are highly activated. Experiments 2A and 2B were conducted to investigate whether M.L. and B.Q. would also show a disproportionate semantic blocking effect in a comprehension task relative to controls. It should be noted that the task in Experiment 2B, using multiple pictures, is like those that have been used with the "refractory access" patients reported by Warrington and colleagues (Warrington & McCarthy, 1983, 1987). These patients show increasing errors in matching words to pictures or spoken words to written words over repeated presentations. The patients studied by Warrington showing refractory access in comprehension are typically quite impaired overall in their language function, and errors rather than reaction times are used as the dependent measure. Given that our patients were much more mildly impaired, reaction times rather than errors were anticipated to be the dependent measure of interest.

For both Experiments 2A and 2B, it was expected that longer reaction times would be obtained for the semantically blocked than for the mixed conditions. In Experiment 2A, it should be more difficult to reject a mismatched semantically related picture–word pair (e.g., dog–bear) than an unrelated picture–word pair (dog–arrow), both due to visual similarity of pictures presented in the blocked condition and due to overlap in the semantic representation between the picture and word. Similarly, in Experiment 2B, it should be more difficult to search through an array of semantically related pictures than a set of unrelated pictures to find one matching a target word. However, there would be no reason to expect that these factors should lead to an increasingly greater difference in reaction times between semantically blocked and mixed conditions over cycles or presentations. Thus, it would be important to show that the semantic blocking effect increases over cycles for the patients and does so to a greater extent than for controls if one wishes to claim that any semantic blocking effect in comprehension derives from the same source as that observed in production.

EXPERIMENT 2A: SEMANTICALLY BLOCKED PICTURE–WORD MATCHING WITH SINGLE PICTURES

This experiment was a comprehension analogue to Experiment 1A, addressing whether the exaggerated semantic blocking effect found for M.L. and B.Q. arises at the lexical or semantic level. Participants were presented with a single picture along with a spoken word and decided whether the word was the name of the picture.

Method

Participants

A total of 14 control participants from the same subject pool as that in Experiment 1 along with M.L., B.Q., and K.V. participated in the experiment. All participants received $10 per hour of participation.

Materials and design

The materials and design were identical to those used in Experiment 1A with the following exceptions. For each picture, a word was presented that either matched or did not match the picture, with 50% of the words within a cycle matching the picture. Spoken words that did not match the picture presented were drawn from the set of picture names included in each block. For example, in a block featuring the category body parts, all answer choices would only include one of the six body part exemplars (i.e., ear, arm, toe, nose, chin, thumb). Similarly, mismatched spoken words within a mixed block would only include one of six exemplars from that particular block (e.g., ear, table, goat, fan, mountain, dress).

Procedure

All pictures were presented using Psyscope 1.2.5 (Cohen et al., 1993). As in Experiment 1A, participants participated in a practice session before the experiment in which they were familiarized with each of the 72 pictures presented during the experiment. The practice session procedure was the same as that in Experiment 1A.

Each trial began the simultaneous presentation of a picture and a spoken word. Participants pressed one of two keys on a Psyscope button box labelled "yes" or "no" with their nondominant hand to indicate whether the word matched the picture and had an unlimited amount of time to make their response. After participants made a response, the experimenter pushed a key to proceed to the next trial, which was followed by a 500-ms RSI.

Experiments 1A and 2A were completed in two different sessions, at least a week apart.

Data analysis

The data were analysed using the same method as that described for Experiment 1A, expect that outliers were classified for all participants as being responses that were 3 standard deviations outside of the participant's mean. The reaction time data were averaged across the "yes" and "no" trials.[8]

Results

See Table 6 for the ANOVA results and Table 7 for condition means.

Controls

Only 1.4% response errors and 1.4% outliers were found for controls. Control participants were slower to respond to items in the semantically blocked condition (1,012 ms) than in the mixed condition (975 ms). Controls also showed decreasing reaction times across cycles. There was no significant Blocking × Cycle interaction. As displayed in Table 7, the regular increase in the blocking effect found in Experiment 1A was not observed in the word–picture matching task. The range of the semantic blocking effects across subjects at each cycle was also quite large—substantially larger than that observed in Experiment 1A.

M.L.

M.L. made only 1.0% response errors, and 3.0% of the data were removed as outliers. M.L. was slower to respond to items in the semantically blocked condition (1,169 ms) than in the mixed condition (994 ms) and showed linear decrease in response times across presentations. The blocking effect increased linearly from 114 ms at Cycle 1 to 177 ms at Cycle 4. M.L.'s semantic blocking effect, as indicated by difference scores, was within the range of controls, except for Cycle 3, which was only 1.4 times (79 ms) greater than the largest difference for controls. When examining log transformed scores, M.L. displayed a similar pattern relative to controls, showing a blocking effect at Cycle 3 that was almost twice as great as the largest difference for controls.

[8] As discussed earlier, Wilshire and McCarthy (2002) found a higher proportion of errors on the "no" trials than on the "yes" trials of a similar task. We also observed a greater relatedness effect for the "no" than the "yes" trials for two of three patients (M.L. and B.Q.). However, we were specifically interested in whether any increasing effect of semantic blocking across cycles would be observed. For each patient, we analysed the data including yes/no as an additional factor. There was no sign of a different pattern of Relatedness × Cycle interaction for the yes versus no trials, as all *F*s were less than 1.0 for the three-way interaction. Hence the data are only reported collapsing across this factor.

Table 6. *ANOVA results (including contrasts) for natural log transformed data by subject* (F_1) *and by items* (F_2) *as a random factor, Experiment 2A*

	Controls						M.L.			B.Q.			K.V.		
	df			*df*			*df*			*df*			*df*		
	Num	*Den*	F_1	*Num*	*Den*	F_2	*Num*	*Den*	F_2	*Num*	*Den*	F_2	*Num*	*Den*	F_2
Blocking	***1***	***13***	***25.18******	***1***	***71***	***10.73*****	***1***	***66***	***51.06******	***1***	***61***	***31.11******	***1***	***66***	***306.95******
Cycle	***3***	***39***	***21.01******	***3***	***213***	***29.13******	***3***	***198***	***126.49******	***3***	***183***	***17.09******	***3***	***198***	***320.50******
Linear	***1***	***13***	***24.06******	***1***	***71***	***64.10******	***1***	***66***	***274.68******	***1***	***61***	***19.11******	***1***	***66***	***1,134.05******
Blocking × Cycle	3	39	1.39	3	213	1.43	***3***	***198***	***47.43******	***3***	***183***	***50.05******	***3***	***198***	***160.94******
Blocking × Linear	1	13	0.51	1	71	0.52	***1***	***66***	***99.19******	***1***	***61***	***82.13******	***1***	***66***	***62.10******

Note: ANOVA = analysis of variance. Num = numerator. Den = Denominator. Effects that were significant are set in bold italic, but in the case of controls only if the effect was significant in both subject and items analyses.
$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

B.Q.

B.Q. made 5.2% response errors, and 3.0% of his data were removed as outliers. B.Q. had slower response times in the semantically blocked condition (1,889 ms) than in the mixed condition (1,567 ms). B.Q. also had a main effect of cycle, which included a linear decrease in response times. Similar to M.L., B.Q. displayed a semantic blocking effect that increased from Cycle 1 to Cycle 3 and then decreased from Cycle 3 to

Table 7. *Semantically blocked single-picture–word matching, Experiment 2A*

		Cycle			
		1	*2*	*3*	*4*
Controls	Blocked	1,048	1,010	985	1,006
	Mixed	1,030	959	952	959
	Difference	18	51	33	47
	Range	−146 to 137	−34 to 180	−24 to 107	−3 to 191
	Difference (nat log)	.019	.048	.031	.039
	Range	−.097 to .092	−.028 to .113	−.030 to .104	−.010 to .101
M.L.	Blocked	1,226	1,131	1,241	1,078
	Mixed	1,112	991	971	901
	Difference	114	140	270	177
	Difference (nat log)	.069	.088	.188	.145
B.Q.	Blocked	1,951	1,741	2,078	1,787
	Mixed	1,697	1,545	1,485	1,539
	Difference	254	196	593	248
	Difference (nat log)	.049	.079	.225	.136
K.V.	Blocked	1,429	1,305	1,333	1,299
	Mixed	1,310	1,312	1,174	1,191
	Difference	119	−7	159	108
	Difference (nat log)	.086	−.001	.120	.083

Note: Response times in ms.

Cycle 4. The semantic blocking effect for B.Q. was slightly larger than M.L.'s (see Table 7), with the exception of Cycle 3, which was almost three times greater than the largest difference for controls. When considering log transformed scores, the blocking effect was almost twice as great as the largest difference for controls.

K.V.

K.V. obtained 2.1% response errors and had 1.7% of his scores removed as outliers. K.V. was slower to make responses in the semantically blocked condition (1,342 ms) than in the mixed condition (1,247 ms). K.V. showed decreasing reaction times across cycle, as well as a linear increase in the blocking effect across cycle. The blocking effect for K.V. was within the range of controls for all cycles except Cycle 3.

EXPERIMENT 2B: SEMANTICALLY BLOCKED PICTURE–WORD MATCHING WITH PICTURE ARRAYS

This experiment was a comprehension analogue to Experiment 1B. The procedure was similar to that used by Warrington and colleagues, with presentation of multiple pictures (Warrington & McCarthy, 1983, 1987). Rate was also manipulated as in Experiment 1B to determine whether the blocking effect would be exaggerated at the faster rate of presentation.

Method

Participants

The same control participants and patients as those in Experiment 1B participated in Experiment 2B. The patients received $12/hour in compensation while the control participants received $10/hour.

Materials and procedure

The materials were the same 72 pictures as those from Experiment 1B. The design of the experiment was the same as that of Experiment 1B except that participants were given an auditory presentation of a word corresponding to one of the pictures in the array. Participants pressed one of six keys on a numeric keypad, arranged in a manner analogous to the pictures on the screen, to indicate the position of the picture on the screen that matched the spoken word. Items were presented at either a short (1,000 ms) or a long (4,000 ms) RSI, with the delay being between the time when the participant responded by pressing a key and the onset of the next auditory presentation. As noted in the procedure for Experiment 1B, participants completed 1B and 2B in the same two sessions.

Data analysis

The data were analysed by the same method as that in Experiment 1B.

Results

See Table 8 for the ANOVA results and Tables 9A and 9B for condition means.

Controls

Control participants made 0.8% response errors and had 1.4% scores removed as outliers. Controls were slower to make responses in the semantically blocked condition (1,245 ms) than in the mixed condition (1,171 ms) and at the long RSI (1,261 ms) than at the short RSI (1,155 ms). Controls also showed a linear decrease in response times across presentations. Controls were also found to have a significant interaction of RSI × Presentation, in which response times decreased much more rapidly across presentations for the short RSI than for the long RSI.

M.L.

M.L. made 1.6% response errors and had 3.0% scores removed as outliers. M.L. was slower to respond in the semantically blocked condition (2,483 ms) than in the mixed condition (1,936 ms) and at the shorter RSI (2,440 ms) than the longer RSI (1,979 ms), in contrast to controls who were slower to respond at the long RSI. The blocking effect increased linearly from 432 ms

Table 8. *ANOVA results (including contrasts) for natural log transformed data by subject* (F_1) *and by items* (F_2) *as a random factor, Experiment 2B*

	Controls						*M.L.*			*B.Q.*			*K.V.*		
	df			*df*			*df*			*df*			*df*		
	Num	*Den*	F_1	*Num*	*Den*	F_2	*Num*	*Den*	F_2	*Num*	*Den*	F_2	*Num*	*Den*	F_2
Blocking	1	8	58.38***	1	71	26.92***	1	71	61.02***	1	71	82.24***	1	71	14.99***
Presentation	3	24	6.17**	3	213	12.95***	3	213	0.99	3	213	0.04	3	213	18.81***
Linear	1	8	7.46*	1	71	35.29***	—	—	—	—	—	—	1	71	50.14***
Rate	1	8	5.39*	1	71	131.58***	1	71	46.46***	1	71	18.97***	1	71	31.31***
Blocking × Presentation	3	24	4.51*	3	213	2.63	3	213	2.97*	3	213	1.60	3	213	0.75
Blocking × Linear	1	8	5.44*	—	—	—	1	71	7.35**	—	—	—	—	—	—
Blocking × Rate	1	8	0.32	1	71	0.06	1	71	3.05	1	71	0.01	1	71	1.91
Presentation × Rate	3	24	3.87*	3	213	4.12**	3	213	0.27	3	213	1.84	3	213	4.45**
Blocking × Presentation × Rate	3	24	0.99	3	213	0.63	3	213	0.31	3	213	0.83	3	213	0.18

Note: ANOVA = analysis of variance. Num = numerator. Den = Denominator. Effects that were significant are set in bold italic, but in the case of controls only if the effect was significant in both subject and items analyses.
$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

at Presentation 1 to 803 ms at Presentation 4. M.L.'s blocking effect was up to 7 times greater than the largest effect for controls at Presentation 4 in terms of raw response times. In terms of log transformed scores, the blocking effect was almost three times as great as the largest difference for controls.

B.Q.

B.Q. made 2.2% response errors and had 2.3% of his data removed as outliers. B.Q. was slower to respond in the semantically blocked condition (3,222 ms) than in the mixed condition (2,293 ms) and at the short RSI (2,918 ms) than at the long RSI (2,597 ms). The blocking effect showed a fluctuating pattern across presentations. The largest blocking effect for B.Q. was nine times greater than the largest effect for controls in terms of raw scores and was almost three times greater than the largest control difference in terms of log transformed scores.

K.V.

K.V. made 0.2% response errors and had 1.0% of his data removed as outliers. K.V. was slower to respond in the semantically blocked condition (1,482 ms) than in the mixed condition (1,368 ms) and at the long RSI (1,484 ms) than at the short RSI (1,366 ms), in contrast to M.L. and B.Q. but similar to controls. K.V. also had a main effect of presentation, which included a significant linear effect of decreasing response times across presentations. K.V. also showed a significant interaction of Presentation × RSI, in which response times decreased much more rapidly across presentations for the short RSI than for the long RSI. The blocking effect was within the range of controls for both raw and natural log transformed response times.

Discussion: Experiment 2

The pattern of results for the control participants in Experiment 2A was somewhat different from

Table 9A. *Semantically blocked array picture–word matching for short RSI, Experiment 2B*

		Presentation			
		1	*2*	*3*	*4*
Controls	Blocked	1,279	1,196	1,163	1,149
	Mixed	1,190	1,115	1,065	1,082
	Difference	89	81	98	67
	Range	−30 to 152	−18 to 212	28 to 233	1 to 132
	Difference (nat log)	.045	.032	.065	.050
	Range	−.033 to .113	−.033 to .113	.016 to .119	−.020 to .104
M.L.	Blocked	2,818	2,757	2,691	2,839
	Mixed	2,255	2,210	2,051	1,898
	Difference	563	547	640	941
	Difference (nat log)	.163	.131	.208	.386
B.Q.	Blocked	3,400	3,307	3,333	3,669
	Mixed	2,284	2,332	2,592	2,425
	Difference	1,116	975	741	1,244
	Difference (nat log)	.300	.248	.127	.279
K.V.	Blocked	1,663	1,350	1,309	1,286
	Mixed	1,521	1,290	1,262	1,244
	Difference	142	60	47	42
	Difference (nat log)	.075	.026	.035	.034

Note: Response times in ms. RSI = response–stimulus interval.

Table 9B. *Semantically blocked array picture–word matching for long RSI, Experiment 2B*

		Presentation			
		1	*2*	*3*	*4*
Controls	Blocked	1,294	1,285	1,304	1,287
	Mixed	1,259	1,244	1,204	1,211
	Difference	35	41	100	76
	Range	−47 to 103	−15 to 120	−3 to 203	26 to 116
	Difference (nat log)	.019	.018	.082	.054
	Range	−.048 to .069	−.018 to .060	−.009 to .184	.020 to .107
M.L.	Blocked	2,154	2,056	2,192	2,359
	Mixed	1,854	1,867	1,656	1,694
	Difference	300	189	536	665
	Difference (nat log)	.109	.048	.216	.243
B.Q.	Blocked	2,937	3,126	2,995	3,008
	Mixed	2,409	2,089	2,206	2,003
	Difference	528	1,037	789	1,005
	Difference (nat log)	.160	.290	.203	.302
K.V.	Blocked	1,688	1,541	1,571	1,447
	Mixed	1,480	1,413	1,379	1,354
	Difference	208	128	192	93
	Difference (nat log)	.104	.068	.136	.062

Note: Response times in ms. RSI = response–stimulus interval.

those in Experiment 1A, as a significant Blocking × Cycle interaction was not obtained. The pattern for controls was similar in Experiments 2B, with an overall significant semantic blocking effect but no interaction with presentation.

Although M.L. obtained a significant Blocking × Cycle interaction in Experiment 2A and a significant Blocking × Presentation interaction in Experiment 2B, the semantic blocking effects were not as exaggerated as those in Experiment 1. In fact, the semantic blocking effects for M.L. were close to or within the range of controls in Experiment 2A, though they were outside their range in 2B for the later cycles. While B.Q. also showed a less exaggerated blocking effect in Experiment 2A than in Experiment 1A, the size of his semantic blocking effects was similar for Experiments 1B and 2B, both of which used multiple-picture presentations. However, in Experiment 2B, B.Q. did not show an obvious pattern of an increasing semantic blocking effect with presentation. Thus, the large main effect of semantic blocking could be due to difficulty that he had in searching through a set of semantically related pictures to find the correct one to match an auditory word. K.V. showed a significant Blocking × Cycle interaction in Experiment 2A, but performed close to or within the range of controls in the single and array word–picture matching tasks.

The pattern of results for Experiment 2B in terms of rate paralleled those found in Experiment 1B. M.L. and B.Q. both showed more difficulty at the faster rate of presentation (M.L. being overall 461 ms slower and B.Q. 321 ms slower) whereas control participants and K.V. again showed the opposite pattern (controls 106 ms faster and K.V. 199 ms faster). As noted earlier for the naming tasks, the different pattern for rate for the controls and K.V. versus M.L. and B.Q. may have resulted because of the relative ease of the task for controls and K.V.

For patients M.L. and B.Q., there was some evidence of an increasing semantic blocking effect in the picture–word matching tasks, though the effects were generally not as large nor did the effects increase as consistently as those in naming. Thus, one might conclude that the difficulty in selection is occurring at a semantic level, which affects both production and comprehension. It is possible, though, that the participants tacitly named the pictures and compared the name of the picture to the spoken word, rather than matching the meaning of the word to the semantic representation of the picture. Some evidence that implicit naming might be involved came from the control participants, who as a group showed a significant correlation between the number of alternative names for a picture and response time ($r = .249$, $p = .035$). If so, the build-up of the semantic blocking effect across cycles might have occurred at the lexical level, from competition during lexical selection in implicit naming. If this is the case, perhaps the semantic blocking effects observed in the naming and matching tasks arise from the same source. The effects of this implicit naming might be smaller and less consistent than that for picture naming in Experiment 1 because such a strategy was optional, and the participants may have used it only on some proportion of the trials.

EXPERIMENT 3: ASSOCIATED WORD–PICTURE MATCHING

In order to address the issue of whether the semantic blocking effect might arise at a semantic level, but to eliminate naming as a possible strategy, an auditory associated word–picture matching task was used in Experiment 3, in which participants heard a spoken word and then selected from a set of pictures the one most associated with the word (e.g., for "kennel" the associated picture would be a dog). Such a task was used by Forde and Humphreys (1997) in a study of a global aphasic patient J.M. They found that J.M showed declining performance across presentations when having to repeatedly access fine-grained semantic information about stimuli, such as in tasks requiring matching of an item to another associatively related item among a set of distractors. They argued for a disruption at the semantic level for J.M. Thus, if the disruption is at a semantic level, we would expect to see an increasing effect across cycle in this task. On the other hand, if the effect in picture naming is at a lexical level, we would not expect to see an increasing effect in this task, as there would seem to be less motivation for implicit naming to be involved. That is, retrieval of the names of the pictures would not provide the participant with the correct picture to select; a comparison of the semantic features of the word and the pictures would still be needed. This experiment was conducted only in the multiple-picture presentation format, as pilot data from a single-picture presentation version indicated that control participants and patients had difficulty making these yes/no judgements as they often responded incorrectly due to some possible but remote or unlikely associative relation between a word and a picture (e.g., saying yes to "beach" matched with a picture of a cloud; the correct pairing with "beach" in this case was a picture of the sun). With the multiple-picture format, it was possible to ask them to select the picture that was most highly associated with the word, thus reducing the ambiguity in response. For this task, longer response times would be expected for the semantically blocked than for the mixed conditions due to the greater difficulty in searching through visually similar pictures and the greater need to rule out remote associations for pictures of semantically related pictures. However, if the semantic blocking effect arises at the semantic level, then M.L. and B.Q. should show similar results to those of Experiment 1, with an increasing blocking effect across presentations, whereas if the semantic blocking effect arises at the lexical level, then M.L. and B.Q. should show no change in the blocking effect across presentations, or at least to an extent no greater than that for the controls.

Method

Participants

A total of 10 control participants (age range: 57–79 years old), some of whom had participated in the earlier experiments, and the patients M.L. and B.Q. participated in the experiment. K.V. was unavailable for testing. The patients received $12/hour in compensation while the control participants received $10/hour.

Materials

The materials were 108 pictures (6 each from 18 semantic categories, see Appendix C) and 108 words associatively related to each picture. The associated words were selected based on the authors' judgements or from the Nelson Association Norms (Nelson, McEvoy, & Schreiber, 1998) and included nouns, adjectives, or verbs that were related to each picture but not from the same semantic category.

Procedure

All participants were first presented with each picture individually and its name, so that they would be familiar with each picture. Participants then participated in a practice session of 24 trials identical to the experimental procedure, but which did not include any of the testing items. Similar to Experiment 2B, participants were presented with an array of six pictures, either all from the same semantic category or from different categories. An auditory word was presented, which was associatively related to one of the pictures, and participants pressed a key on a numeric keypad to indicate the pictured object having the strongest relation with the word. After the participant had made a response, a blank screen was presented for 1,500 ms, and the same set of pictures was presented again in a different arrangement. Each auditory word was presented four times in a block for a total of 24 trials in a block. The presentation of items in a block was made in a partial Roman block design, with no items being presented twice in succession. Blocks and items were presented in the same order for every participant. Participants were given the opportunity to rest after each block. Participants completed the experiment in one session, seeing half of the items in a semantically blocked context first and the other half of the items in a mixed context first. Only the presentation rate corresponding to the fast rate in the other experiments was used, because the data from those experiments suggested that M.L. and B.Q. would be likely to show a greater semantic blocking effect at the faster presentation rate.

Data analysis
Errors were removed from the analysis. Outliers were again defined as values that were 3 standard deviations from the condition mean for each participant. A repeated measures ANOVA with items as a random factor was again performed for patients, and both an item and subject analysis were performed for controls.

Results

See Table 10 for the ANOVA results and Table 11 for condition means.

Controls
Controls made 1.6% response errors and had 1.4% of the data removed as outliers. Controls were slower to respond in the semantically blocked condition (3,332 ms) than in the mixed condition (3,116 ms). Controls showed a linear decrease in response times across presentations. While the Blocking × Cycle interaction was significant in the analysis by subjects, it was far from significant in the analysis by items. Moreover, to the extent that there is an interaction, the pattern in the raw difference scores revealed no evidence of a steadily increasing effect. Instead, the blocking effect decreased from Cycle 1 to Cycle 3 and then at Cycle 4 returns to the about the level of the effect at Cycle 1. In terms of log transformed scores, there was some increase from Cycle 1 to Cycle 2, but then the effect remained stable thereafter.

M.L.
M.L. made 1.7% response errors and had 2.1% of his data excluded as outliers. M.L. was slower to respond to items in the semantically blocked condition (5,447 ms) than in the mixed condition (4,986 ms). M.L. showed a linear decrease in reaction times across cycle. However, the Blocking × Cycle interaction was far from significant. Like controls, in terms of log transformed data, he showed an increase in the blocking effect from Cycle 1 to Cycle 2 and a relatively stable effect thereafter. While M.L.'s largest blocking effect at Cycle 3 in nontransformed scores was 1.33 times greater than the largest difference for controls, the blocking effect in terms of log transformed scores was within the range of controls at each cycle.

B.Q.
B.Q. made 1.4% response errors and had 1.4% of his data excluded as outliers. B.Q. was slower to respond in the semantically blocked condition (7,666 ms) than in the mixed condition (6,076 ms). B.Q. also showed a linear decrease in

Table 10. *ANOVA results (including contrasts) for natural log transformed data by subject* (F_1) *and by items* (F_2) *as a random factor, Experiment 3*

	Controls						*M.L.*			*B.Q.*		
	df			*df*			*df*			*df*		
	Num	*Den*	F_1	*Num*	*Den*	F_2	*Num*	*Den*	F_2	*Num*	*Den*	F_2
Blocking	***1***	***9***	***93.43******	***1***	***107***	***30.28******	***1***	***84***	***10.37*****	***1***	***87***	***32.30******
Cycle	***3***	***27***	***108.15******	***3***	***321***	***156.95******	***3***	***252***	***54.82******	***3***	***261***	***22.52******
Linear	***1***	***9***	***154.78******	***1***	***107***	***214.35******	***1***	***84***	***82.57******	***1***	***87***	***49.31******
Blocking × Cycle	3	27	3.69*	3	321	0.58	3	252	1.14	3	261	0.24
Blocking × Linear	1	9	7.97*	—	—	—	—	—	—	—	—	—

Note: ANOVA = analysis of variance. Num = numerator. Den = Denominator. Effects that were significant are set in bold italic, but in the case of controls only if the effect was significant in both subject and items analyses.
*$p < .05$. **$p < .01$. ***$p < .001$.

Table 11. *Semantically blocked associated word–picture matching, Experiment 3*

		Cycle			
		1	*2*	*3*	*4*
Controls	Blocked	3,769	3,247	3,170	3,143
	Mixed	3,540	3,027	2,971	2,925
	Difference	229	220	199	218
	Range	−16 to 376	96 to 582	109 to 424	144 to 418
	Difference (nat log)	.050	.069	.062	.068
	Range	−.003 to .081	.034 to .156	.043 to .124	.045 to .126
M.L.	Blocked	7,239	5,138	4,828	4,583
	Mixed	6,950	4,702	4,262	4,028
	Difference	289	436	566	555
	Difference (nat log)	.075	.107	.113	.112
B.Q.	Blocked	9,579	7,566	6,867	6,653
	Mixed	7,392	5,847	5,590	5,475
	Difference	2,187	1,719	1,277	1178
	Difference (nat log)	.215	.247	.184	.156

Note: Response times in ms.

response times across cycles; however, the Blocking × Cycle interaction was far from significant. In contrast to the patterns obtained in Experiments 1 and 2, B.Q.'s largest blocking effect occurred in Cycle 1 and continuously decreased across subsequent cycles (see Table 11). While the largest blocking effect for B.Q. at Cycle 1 was more than 5 times greater than the largest difference for controls in nontransformed scores (almost 3 times greater in log transformed scores), the effect decreased by Cycle 4, as it was 3 times greater in nontransformed scores and 1.2 times greater in log transformed scores than the largest difference for controls.

Discussion: Experiment 3

The results of this experiment were consistent across controls and patients. All participants had significant effects of semantic blocking and showed decreasing response times across cycles, but showed no significant change in the size of the blocking effect across presentations. M.L. was within the range of controls in the size of the semantic blocking effect for Cycles 1 and 2 for the untransformed scores and for all cycles for the transformed scores. B.Q. was outside the range of controls in terms of the size of the semantic blocking effect across all cycles, but if anything showed a reduction in the size of the blocking effect at later cycles.

In contrast to Experiments 1 and 2, the performance of M.L. and B.Q. was remarkably similar to that of the controls in Experiment 3. In Experiment 3, participants were required to repeatedly retrieve semantic information about auditory words and to compare this to presented pictures. Unlike what was found in Experiment 2, where controls showed a significant correlation between number of alternate names and response times, response times in Experiment 3 were not correlated with any lexical variable (including name agreement, number of alternate names, and word frequency) for the controls as a group or for patients (all ps $> .16$). The normal pattern for M.L. and B.Q. in Experiment 3 thus supports the hypothesis that the semantic blocking effect observed for these patients is arising at the lexical level, due to the simultaneous activation of several lexical items, rather than at the semantic level.

GENERAL DISCUSSION

This series of experiments was conducted to assess whether M.L. and B.Q., like other patients with preserved single-picture naming but disrupted production of words in context, would show exaggerated semantic blocking effects in production and, if so, whether these effects would extend to comprehension. From these results, we wished to address the two issues of at what level of representation semantic blocking effects arise in production (lexical or semantic) and what the nature of this disruption is (overactivation or overinhibition). Experiment 1 documented that both M.L. and B.Q. did show greatly exaggerated semantic blocking effects in their naming latencies, which increased across presentations. Experiment 2 showed that, while they did demonstrate large effects of semantic blocking in a comprehension task, the size of their semantic blocking effects did not consistently increase across cycles, and, in terms of natural log transformed scores, their effects were often within the range of controls. Experiment 3, a comprehension task that required participants to access the object's meaning rather than its name in order to match the picture to a spoken word (Forde & Humphreys, 1997), showed that M.L. and B.Q. performed more similarly to controls than they did in Experiments 1 and 2, showing decreasing reaction times across cycles in both the blocked and mixed conditions and no interaction of blocking with cycle.

As discussed in the Introduction, a variety of explanations have been offered for the exaggerated semantic blocking effects that have been previously demonstrated for patients with good single-picture naming but a deficit in naming in context. Like Schnur et al. (2006), we have attributed the exaggerated semantic blocking effect in the case of M.L. to overactive representations. In contrast, McCarthy and Kartsounis (2000) argued for refractory behaviour of lexical representations after their activation. As discussed earlier, Schnur et al. attempted to distinguish between the overactivation and refractory access accounts in an analysis of errors across cycles. Hamilton and Martin (2005) argued for M.L. having a difficulty in inhibiting representations, based on his exaggerated difficulty in rejecting target items that had been presented on an earlier list in the recent negatives task. Thus, the exaggerated blocking effect for M.L. (and B.Q.) in Experiment 1 would seem to be unlikely to be due to overinhibition. Although neither of these findings would definitively rule out refractory access of lexical representations for these patients, as some of the refractory access account with additional assumptions could be made, they do constitute mounting evidence against such an account.

Another issue concerns the level or levels affected, which may give rise to the selection difficulties and semantic blocking effects observed in left frontal patients with damage to the LIFG. Thompson-Schill and colleagues (Kan & Thompson-Schill, 2004; Novick, Trueswell, & Thompson-Schill, 2005) have argued that the executive selection mechanism deficient in such patients affects multiple verbal representational levels, including at least lexical and semantic levels. The results from the current study contradict that account, as the patients showed the most exaggerated growth in the semantic blocking effect when lexical access was required (naming), a greatly reduced effect when lexical access was a potential strategy (word–picture matching), and no effect when lexical access would not be beneficial (associated word–picture matching). These findings support the deficit that gives rise to the exaggerated semantic blocking effect in naming being due to a deficit at the lexical level.

We have specifically argued that M.L. may have difficulty with postselection lexical inhibition, such that that previously produced words remain strong competitors for current targets, with the effects being exacerbated when the prior words are semantically related to the target. Another proposal by Thompson-Schill and colleagues (e.g., Thompson-Schill & Botvinick, 2006) argues in favour of a top-down mechanism that acts to change activation weights based on the task demands. Although the Thompson-Schill account does well in accounting for performance on interference tasks, such as the Stroop and recent negatives task, among others, it is not clear that the account would predict the findings from the patients in the semantic blocked naming task. In this task, participants always make the response that should be most congruent with the picture—that is, its name. In order for this hypothesis to apply to the semantically blocked naming affect, one would have to assume that as activation of competitors grows, adjustments to the weighting mechanism are required to give an ever greater weighting to activation deriving from the picture. One would have to surmise that patients with LIFG impairments have difficulty making these readjustments.

B.Q.'s pattern was similar to M.L.'s across experiments, with his effects often being even larger than those for M.L. There is also evidence of an inhibitory deficit for B.Q. Given B.Q.'s extensive left lateralized lesion that includes temporal regions as well, one might have predicted that he would show a different deficit from that for M.L. However, given the similarity between M.L. and B.Q., especially in Experiments 1 and 3, it would seem more parsimonious to assume that both B.Q. and M.L. have a similar underlying deficit, but that the deficit is simply worse for B.Q. than M.L., perhaps worsened by damage to other areas, resulting in his greater degree of nonfluency in spontaneous speech and his sometimes greater semantic blocking effects. B.Q.'s larger overall semantic blocking effect is also consistent with the finding from Schnur et al. (2005) that damage to temporal regions is associated with a greater overall semantic blocking effect in production.

A final issue concerns what these results indicate about our previous claims of a semantic short-term memory (STM) deficit for patient M.L. (e.g., Martin & He, 2004). Hamilton and Martin (2005, 2007) suggested that M.L.'s STM deficit might derive from his difficulty in inhibiting irrelevant verbal representations. One might hypothesize that M.L. shows excessive interference among items, with prior lists intruding into the recall of current lists, due to the inability to inhibit previous list representations. Even within a list, other items might compete for retrieval with the current items being recalled. According to this view, the inhibitory deficit is primary, and the STM deficit follows from it. Could such a hypothesis account for the other patterns of deficits that we have observed with M.L. and other semantic STM deficit cases in language production and comprehension? As discussed in Martin (2007), such an inhibitory deficit can provide an account of phrase and sentence production deficits observed for these patients (e.g., Martin & Freedman, 2001; Martin et al., 2004), given the assumption of an important role for postselection inhibition in some models of language production. That is, perhaps M.L.'s difficulty in producing the phrase "small green leaf" arises from the incomplete or absent postselection inhibition of initial words of the phrase in order to successfully select and retrieve lexical information for subsequent words in the phrase. On the other hand, the comprehension data for these patients present more of a challenge to such an inhibition account. For instance, semantic STM deficit patients have shown difficulty detecting the anomaly between "rusty" and "swimsuit" for phrases with several intervening adjectives (e.g., "rusty old red swimsuit") (Martin & He, 2004; Martin & Romani, 1994). It is hard to see how a deficit in inhibiting verbal representations could lead to difficulty in detecting the anomaly at a greater distance. Persisting activation of earlier words in a phrase would seem to help comprehension rather than hurt it. Overly rapid decay of semantic representations would seem to provide a more natural explanation. Clearly, additional cases need to be studied to determine whether the inhibitory deficit necessarily co-occurs with the semantic STM deficit and the characteristic production and comprehension patterns that have previously been reported. It is possible that two semantic control functions have been disrupted in M.L. and that a dissociation will be evident in other cases.

With regard to the initial question motivating this study, it seems that there is considerable similarity between patient M.L. and several other patients reported in the literature who show a naming deficit in context. As suggested by Wilshire and McCarthy (2002), this deficit could be the source of nonfluency in speech and evident word-finding difficulties. If, as we have hypothesized, M.L. cannot inhibit lexical representations once he has produced them, he will have great difficulty in selecting upcoming words in discourse. This difficulty should be exacerbated when the words are from the same semantic category, as spreading activation will serve to further boost the activation of previously produced lexical items that are related to the current target.

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APPENDIX A

Semantic categories and items in Experiments 1A and 2A

Animals	*Appliances*	*Body parts*	*Clothing*	*Food*	*Furniture*
bear	fan	arm	coat	bread	bed
cat	iron	chin	dress	cake	chair
dog	radio	ear	glove	cheese	couch
goat	scales	nose	hat	pie	crib
horse	toaster	thumb	skirt	shrimp	stool
skunk	vacuum	toe	sock	soup	table

Nature	*Plants*	*Roles*	*Shapes*	*Toys*	*Utensils*
cloud	bush	bride	arrow	ball	cup
mountain	cactus	clown	circle	bat	fork
pond	fern	judge	cone	blocks	glass
sun	flower	nun	cross	doll	knife
volcano	mushroom	nurse	heart	kite	pitcher
waterfall	tree	soldier	star	top	spoon

APPENDIX B

Semantic categories and items in Experiments 1B and 2B

Animals	*Appliances*	*Birds*	*Clothing*	*Food*	*Fruit*
cat	iron	chicken	belt	bread	apple
dog	radio	eagle	glove	cake	banana
mouse	refrigerator	owl	hat	cheese	grapes
rabbit	stove	parrot	pants	hamburger	pear
squirrel	television	peacock	shoe	pizza	pineapple
wolf	toaster	turkey	sock	sandwich	strawberry

Instruments	*Tools*	*Toys*	*Utensils*	*Vegetables*	*Vehicles*
bell	drill	ball	bowl	carrot	airplane
drum	hammer	jump rope	cup	celery	bicycle
flute	pliers	kite	fork	corn	boat
guitar	saw	skate	glass	lettuce	bus
piano	screwdriver	top	plate	onion	car
trumpet	wrench	yoyo	teapot	peas	train

APPENDIX C

Semantic categories and items in Experiment 3

Category	*Picture*	*Word*
Animals	bear	honey
Animals	cat	scratch
Animals	dog	kennel
Animals	horse	saddle
Animals	lion	jungle
Animals	skunk	odor
Appliances	fan	breeze
Appliances	iron	wrinkle
Appliances	radio	music
Appliances	scales	measure
Appliances	television	channel
Appliances	vacuum	carpet
Birds	canary	sing
Birds	duck	lake
Birds	owl	wise
Birds	penguin	snow
Birds	rooster	dawn
Birds	turkey	Thanksgiving
Body parts	arm	sleeves
Body parts	ear	noise
Body parts	eye	blink
Body parts	finger	ring
Body parts	leg	kick
Body parts	nose	smell
Buildings	castle	princess
Buildings	church	priest
Buildings	house	mortgage
Buildings	igloo	Eskimo
Buildings	tent	camp
Buildings	tepee	Indian
Clothing	belt	buckle
Clothing	cap	baseball
Clothing	glove	hand
Clothing	jersey	umpire
Clothing	shoe	walk
Clothing	tie	office
Foods	bread	toast
Foods	cake	birthday
Foods	cheese	mouse
Foods	eggs	Easter
Foods	popcorn	movie
Foods	spaghetti	Italy
Fruits	apple	teacher
Fruits	banana	monkey
Fruits	grapes	wine
Fruits	lemon	sour
Fruits	orange	Florida
Fruits	pineapple	Hawaii

Category	*Picture*	*Word*
Furniture	bed	sleep
Furniture	chair	sit
Furniture	crib	infant
Furniture	desk	work
Furniture	dresser	clothing
Furniture	lamp	light bulb
Nature	lightning	strike
Nature	mountain	hike
Nature	pond	fish
Nature	rain	umbrella
Nature	sun	beach
Nature	volcano	lava
Plants	cactus	desert
Plants	fern	swamp
Plants	flower	pollen
Plants	mushroom	fungus
Plants	rose	thorn
Plants	tree	shade
Roles	bride	wedding
Roles	clown	circus
Roles	judge	court
Roles	nun	convent
Roles	nurse	hospital
Roles	soldier	army
Tools	hammer	nail
Tools	ladder	climb
Tools	paintbrush	drip
Tools	scissors	cut
Tools	screwdriver	turn
Tools	shovel	dig
Toys	ball	bounce
Toys	balloon	pop
Toys	bat	swing
Toys	bicycle	pedal
Toys	blocks	build
Toys	top	spin
Utensils	bowl	cereal
Utensils	kettle	steam
Utensils	oven	bake
Utensils	pitcher	lemonade
Utensils	spoon	stir
Utensils	rolling pin	flatten
Vegetables	carrot	rabbit
Vegetables	corn	harvest
Vegetables	lettuce	salad
Vegetables	onion	tear
Vegetables	pea	pod
Vegetables	potato	fries

(*Continued overleaf*)

Category	*Picture*	*Word*
Vehicles	airplane	stewardess
Vehicles	boat	dock
Vehicles	bus	school
Vehicles	car	Ford
Vehicles	truck	movers
Vehicles	train	conductor
Weapons	ax	chop
Weapons	bomb	explode
Weapons	bow	arrow
Weapons	gun	shoot
Weapons	knife	stab
Weapons	rope	strangle