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Brief article

Interfering neighbours: The impact of novel word learning on the identification of visually similar words

Jeffrey S. Bowers[a,*], Colin J. Davis[a,b], Derek A. Hanley[a]

[a]Department of Experimental Psychology, University of Bristol, 8 Woodland Rd, Clifton, Bristol BS8-1TN, UK
[b]Macquarie University, 8 Woodland Rd, Clifton, Bristol, BS8-1TN, UK

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Abstract

We assessed the impact of visual similarity on written word identification by having participants learn new words (e.g. BANARA) that were neighbours of familiar words that previously had no neighbours (e.g. BANANA). Repeated exposure to these new words made it more difficult to semantically categorize the familiar words. There was some evidence of interference following an initial training phase, and clear evidence of interference the following day (without any additional training); interference was larger still following more training on the second day. These findings lend support to models of reading that include lexical competition as a key process.

Keywords: Orthographic neighbours; Cascaded; Inhibition; Neighbourhood size; Word learning; Consolidation

Many theories of visual word perception include lexical competition as a key process (e.g. Davis, 1999; Grainger & Jacobs, 1996; McClelland & Rumelhart, 1981). According to these theories, multiple word representations become active and compete with each other during the identification of a printed word. Identification is achieved when a single word becomes dominantly active and suppresses the activity of other words.

An obvious prediction of this approach is that form similarity should impede word identification. For example, the identification of BANISH should be slowed relative to

* Corresponding author.
E-mail address: j.bowers@bris.ac.uk (J.S. Bowers).

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BANANA, all else being equal, given that the activation of BANISH is partially inhibited by the form-similar word VANISH, whereas BANANA has no form-similar competitors. Indeed, this prediction has inspired a great deal of research into the role of neighbours on word identification—neighbours are defined as words that differ in a single letter substitution (such as BANISH and VANISH; Coltheart, Davelaar, Jonasson, & Besner, 1977). Two related questions have been considered, namely, the impact of the number of neighbours (neighbourhood size), and the impact of the relative frequency of these neighbours (neighbour frequency). The assumption of this research is that identification should be impaired for words with larger neighbourhoods or higher frequency neighbours, if competition plays a role in the process.

Unfortunately, the neighbourhood size and frequency results have been quite mixed, making it difficult to draw any strong conclusions. There has been a tendency for facilitatory effects in English and inhibitory effects in French and Spanish (cf. Andrews, 1997; Perea & Rosa, 2000), leading some to argue that competition plays a more important role in some languages compared to others (e.g. Andrews, 1997; Siakaluk, Sears, & Lupker, 2002; Ziegler & Perry, 1998).

Another explanation of the mixed results is that participants may have adopted different response strategies across experiments (Grainger & Jacobs, 1996). On this account, neighbourhood size facilitates performance when participants can respond on the basis of overall lexical activity rather than via identification of the specific target word. In this case, words with large neighbourhoods have an advantage, assuming that they generate more lexical activity than words with small neighbourhoods. By contrast, when unique identification is required, neighbourhood similarity impairs performance.

Still another (and less interesting) explanation for the mixed results is methodological. The standard approach to studying neighbourhood effects has been to select two sets of words that differ in their neighbourhood characteristics, but are matched on other relevant dimensions, such as frequency and word length. However, most studies have not matched on a wide range of relevant factors, including morphological complexity, imageability, and age-of-acquisition. More generally, researchers are far from characterizing all the variables that influence word identification, and thus any attempt to match items across conditions is problematic (e.g. Cutler, 1981). As Forster and Shen (1996) noted: ‘Given the difficulty that investigators are evidently experiencing, one is forced to consider the possibility that in some, or perhaps in all experiments dealing with this issue, the experimental materials are inadequately matched on some known or unknown variable …’ (p. 709).

Equally importantly, much of this work has been carried out under a misunderstanding regarding the predictions of competitive models. Studies of neighbourhood size have generally contrasted words with few and many neighbours, and studies of neighbour frequency have tended to include words with multiple neighbours, with the frequency of one or more of the neighbours varied. However, competitive network models like IA (interactive activation, McClelland & Rumelhart, 1981) and SOLAR (self-organising lexical acquisition and recognition, Davis, 1999) predict that the critical contrast is between words that have no neighbours (‘hermits’) and words that have one or more neighbours. By comparison, the models predict little or no difference between words with one neighbour and words with several neighbours (Davis & Andrews, 1996). Larger neighbourhoods do not provide additional competition due to the fact that the total amount of activity at the word level is roughly normalized—as a consequence, the inhibition of any given neighbour to a target is diluted in proportion to the number of neighbours. Thus, in order to evaluate the prediction made by competitive models, it is necessary to use hermit words. Very few studies have tested this condition. Furthermore, a valid test of this condition requires having a psychologically accurate definition of a 'neighbour'. The conventional definition of a neighbour considers only words formed by the substitution of a single letter (e.g. Coltheart et al., 1977). However, research using English stimuli in lexical decision tasks has shown inhibitory effects of higher frequency 'neighbours' formed by letter transpositions as well as significant facilitatory priming effects from nonword primes formed by letter transpositions (i.e. jugde is a highly effective prime for JUDGE; Perea & Lupker, 2003a,b, 2004) regardless of the fact that transpositions are not neighbours in the conventional sense. In addition, inhibitory effects due to 'neighbours' created by letter deletion (e.g. STABLE–TABLE; Bowers, Davis, & Hanley; 2005; Davis & Taft, submitted for publication), and letter addition (e.g. URN–TURN; Bowers et al., 2005) have been observed in lexical decision and semantic categorization tasks. If, as these results suggest, the conventional definition of a neighbour is incorrect, it is not clear that any of the experiments, in any language, have selected words that provide an adequate test of the critical hypothesis that words with one or more neighbours will be identified more slowly than hermit words.

1. Addressing the stimulus-matching problem

The optimal way to overcome stimulus matching problems is to employ a methodology that compares a word with itself. A few studies have taken this approach and have reported evidence supporting lexical inhibition between neighbours. One such approach is to compare responses to target words that are preceded by a masked prime that is either a neighbouring word (e.g. able-AXLE) or an unrelated word (e.g. door-ABLE). Several lexical decision studies have reported inhibitory effects of a neighbour prime, particularly when the prime is of higher frequency than the target (e.g. Brysbaert, Lange, & van Wijnendaele, 2000; Davis & Lupker, submitted; De Moor & Brysbaert, 2000; Grainger, Colé, & Segui, 1991; Segui & Grainger, 1990; for related findings see Hinton, Liversedge, & Underwood, 1998; Pugh, Rexer, Peter, & Katz, 1994). This agrees with the prediction of competitive network models like IA and SOLAR (Davis, 2003; Davis & Lupker, submitted for publication). It should be noted, however, that facilitatory neighbourhood priming effects have also been reported when the primes and targets are relatively long (eight or nine letters) and the nonwords foils were orthographically dissimilar to words (Forster & Veres, 1998). The IA model also predicts facilitation under these conditions (Davis & Lupker, submitted for publication).

Although the above studies used methodologies that compare a target word with itself, they involved comparisons of slightly different stimulus displays (e.g. targets preceded by different primes). Indeed, given that the critical primes in these displays were competitors to the targets, it is possible that the inhibition is a by-product of these specific conditions, and do not reflect the normal processes that are engaged for unprimed displays.

Another technique for comparing a word with itself in an unprimed methodology was demonstrated by Zagar and Mathey (2000), who took advantage of the fact that accents in French are shown only on lowercase letters, and hence changing typecase sometimes changes a word's neighbourhood. While this elegant methodology provided nice evidence for lexical competition in French, it cannot be used with English stimuli, and hence cannot rule out the possibility that inhibitory processes are stronger in languages other than English (e.g. Andrews, 1997; Siakaluk et al., 2002; Ziegler & Perry, 1998).

In the present paper, we adopted a different approach in order to compare hermit words with words that have one neighbour. Like the above studies we employed a within-word manipulation, comparing a word with itself, but we manipulated the presence of a lexical neighbour by introducing new words into participants' lexicons. That is, we introduced new orthographic word forms that are neighbours of familiar words that have no pre-existing neighbours (i.e. words that not only have no substitution neighbours, but also have no transposition neighbours, addition neighbours or deletion neighbours).[1] For instance, we trained participants on the novel word BANARA, a neighbour of the hermit word BANANA. According to competitive models of word identification, the introduction of BANARA should slow down processing of BANANA relative to itself prior to the training, as it would change its neighbourhood from zero to one. It should be noted that this same approach has been used to assess the role of competition in spoken word identification (Gaskell & Dumay, 2003).

In the current study, participants learned the new word forms by repeatedly reading and typing them, and they responded to the familiar targets in a semantic categorization task. We reasoned that learning the new orthographic pattern BANARA does not provide any information about how to classify BANANA in a semantic task. Accordingly, any impact of the new neighbours on classifying the targets would likely reflect lexical competition rather than some form of episodic influence. Furthermore, unlike the lexical decision task, the semantic categorization task requires the unique identification of the target word. Accordingly, any competitive process cannot be masked by responding on the basis of overall lexical activity (Grainger & Jacobs, 1996).

2. Method

2.1. Participants

Thirty participants were recruited from the University of Bristol paid participant pool; they were paid £14 for their participation. All were native English speakers, and had normal or corrected-to-normal eyesight.

[1] 'Deletion' neighbours are defined as words that are formed by deleting a single letter from any position to the target word. 'Addition' neighbours are defined as words that are formed by adding a single letter (at any position) to the target word, with the exception of plurals, which we did not count as addition neighbours (e.g. BANANAS is not counted as an addition neighbour of BANANA).

2.2. Materials and design

We selected 40 critical hermit words that had no substitution, transposition, deletion or addition neighbours. All items were six letters in length and relatively low in frequency (CELEX written frequency between 3 and 17 counts per million). Half of the critical items referred to naturally occurring entities (e.g. PIGEON, BANANA), and half to artefacts (i.e. 'manmade' entities, e.g. ANCHOR, CRADLE).

The to-be-learned neighbours were constructed by substituting one internal letter of each critical word to form a pronounceable non-word. The full set of critical words and non-words is listed in the Appendix. An additional set of 40 six-letter, low frequency filler words was selected, half of which referred to natural entities and half to artefacts. These items were included to reduce the proportion of words that were orthographically related to the to-be-learned neighbours. Stimuli were presented in 20 point Times New Roman font, using the DMDX software package (Forster & Forster, 2003).

During the training phase, each participant learned 20 new words: Ten were neighbours of the critical words from the Natural category and ten were neighbours of the critical words from the Artefact category. Two counterbalanced files were created, so that each critical word gained a neighbour for half the participants and remained a hermit word for the other half of the participants.

2.3. Procedure

The experiment was run on two consecutive days. Day 1 began with a learning phase, which was the typing task. Participants were informed that a novel word would appear onscreen, and were instructed to type the word as quickly and accurately as possible. On each trial a plus sign was displayed for 500 ms, followed by a blank screen for 350 ms, followed by the non-word which the participant had to type. The non-word remained on the screen until the participant finished typing and pressed the 'return' key. Participants were able to view the letters they typed and correct any errors by using the backspace key. The 20 non-words for each participant were presented in a randomised order within each block. At the end of each block the full list of items appeared on the screen, and the participants were asked to read through the list. Altogether there were 10 blocks of training, plus one additional practice block presented at the beginning of the learning phase.

Following the typing task participants performed the semantic categorisation task. They were asked to classify each of the the 40 critical words and 40 filler words as members of the Natural or Artefact categories as quickly and accurately as possible, by pressing the left or right shift keys. The category labels natural and artefact were presented on the bottom left and righthand corners of the screen to remind the participant of the shift key assignments. For half of the participants the right shift key was used for the Natural category and the left shift key for the Artefact category; the assignment of keys was reversed for the other participants. Each trial began with a fixation point displayed for 800 ms, followed by a blank screen for 350 ms, followed by the target for 500 ms. Feedback was provided after each trial.

On Day 2 participants performed the semantic categorization task again, and then completed another 10 blocks of training on the typing task. Finally, they were tested on the semantic categorization task once more. Apart from the order of items (which was fully randomised) the training and categorization tasks were identical on days 1 and 2.

3. Results

We conducted separate analyses on the RT and error data. Two participants with overall error rates greater than 20% on the semantic categorization task were excluded from the analyses, and RTs greater than 1500 ms or less than 300 ms were considered outliers and were removed from the analyses (1.1% of trials). Table 1 shows the mean correct RT and error rates for the words that remained hermits and the words that gained a neighbour (the 'non-hermit' condition), for each of the three repetitions of the semantic categorization task. Overall, non-hermits were categorised more slowly than words that remained hermits. In the first categorization task, this difference was not significant by participants, $t1(27)=1.0$, $P=0.16$, but was marginally significant by items, $t2(40)=1.6$, $P=0.06$. In the second categorization task the difference was significant both by participants and by items, $t1(26)=3.3$, $P<0.01$, $t2(39)=2.9$, $P<0.01$. The difference was also significant in the third categorization task, $t1(26)=4.8$, $P<0.001$, $t2(39)=2.1$, $P<0.05$. These findings support the notion that the new neighbours were activated and competed for identification with the targets. Analyses of the error scores revealed no difference between hermits and non-hermits for the first or third categorization tasks, $t\text{s}<1$, and an inhibitory effect during the second categorization task, $t1(26)=2.3$, $P<.05$, $t2(39)=2.1$, $P<0.05$ (that is, participants made more errors to words that gained a neighbour than to words that remained hermits). Thus, the inhibitory RT effects cannot be attributed to a speed-accuracy trade off.

As can be seen in Table 1, the magnitude of the inhibitory RT effect increased across the three repetitions of the task, from 17 to 33 ms, to 48 ms. The linear trend was

Table 1
Mean RTs (ms) and error rates (%) for the hermit and non-hermit conditions in the three semantic categorisation tasks

Semantic categorisation task	Condition	RT	ER
1	Hermit	730	7.9
	Non-hermit	747	7.8
	Difference	−17	0.1
2	Hermit	684	3.8
	Non-hermit	717	7.3
	Difference	−33	−3.5
3	Hermit	649	4.7
	Non-hermit	697	4.3
	Difference	−48	0.4

statistically significant, i.e. the inhibitory effect in the third repetition of the semantic categorization task was greater than that in the first, $t1(26)=1.7$, $P<0.05$, $t2(39)=2.7$, $P<0.01$.[2] The difference between the first and second, and the second and third repetitions was not significant, $t1(26)=1.4$, $P=0.09$, $t2(39)=1.1$, $P>0.05$, and $t1(26)=1.1$, $P>0.05$, $t2(39)=.93$, $P>0.05$, respectively.

4. Discussion

The impact of form similarity is an important unresolved issue in the study of visual word identification. As noted above, much of the research on this topic is limited in two respects, and this may have contributed to the mixed findings. First, the standard approach to studying neighbourhood effects relies on stimulus matching procedures that are very difficult to implement successfully (e.g. Cutler, 1981; Forster & Shen, 1996). Second, past studies have not tested the critical contrast, which is between words with no neighbours and words with one or more neighbours.

The present study avoided these problems by varying neighborhoods from zero-to-one and comparing performance within items (e.g. comparing BANANA with BANANA). This was achieved by training participants on new words (e.g. BANARA) that were neighbors of hermit words ('hermits' in the strict sense that they had no substitution, transposition, deletion or addition neighbours). Under these conditions, a weak inhibitory effect was observed after training on the first day. This inhibitory effect increased without any further training on the second day, and grew larger still following more training on the second day. We take these findings as strong evidence that competition between orthographically similar forms exerts an inhibitory effect on visual word identification.

One possible objection to this conclusion is that the observed inhibitory effects reflect biases or strategies based on episodic memory, rather than lexical competition. It is important to emphasize that we used the semantic categorization task in order to reduce any episodic contributions to performance. It is difficult to see how the repeated typing of BANARA should bias a participant to categorize BANANA as either naturally occurring or artificial. Furthermore, the data speak against the view that episodic memory contributed to the inhibitory effects. Participants completed the first and second semantic categorization a day apart following a single training session on Day 1, and yet the size of the inhibition was larger following the delay. If episodic memory was responsible for the inhibitory effects, these effects would be expected to be reduced on Day 2.

It is interesting to note that similar training methodologies have been used to assess the role of competition in spoken word identification (Gaskell & Dumay, 2003; Magnuson, Tanenhaus, Aslin, & Dahan, 2003). For example, Gaskell and Dumay (2003) exposed participants to spoken non-words such as "cathedruke" in a phoneme monitoring task. After training, these items slowed down auditory lexical decisions to

[2] One participant attended the first day of the experiment but not the second. This participant was excluded from the analyses of the differences across categorisation tasks.

form-related words (“cathedral”). According to the authors, the introduction of ‘cathedruke’ extended the uniqueness point of ‘cathedral’, with ‘cathedral’ and ‘cathedruke’ competing for identification. Interestingly, they also found that the size of the interference increased over time, and they attributed this to a consolidation process during which the new words became lexicalised. A similar consolidation process may account for the increased interference that we observed on Day 2, prior to retraining.

In sum, the present results provide strong evidence for inhibition between form-similar words, using a methodology that avoids stimulus-matching problems. This lends support to models that include lexical competition as a core process in word identification (e.g. Davis, 1999; McClelland & Rumelhart, 1981).

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Appendix. Experimental Stimuli (Words in CAPS are the critical items in the semantic categorisation task, item in lower-case are the stimuli learned in the training phase).

Natural Words	New Word	Artefact Words	New Word
PIGEON	Pigern	ANCHOR	amchor
WALNUT	Walnot	TARMAC	talmac
GARLIC	Garnic	CRADLE	cragle
POTATO	Potato	SLEEVE	sleere
FOSSIL	Fostil	HELMET	holmet
MEADOW	Mearow	COFFIN	colfin
KIDNEY	Kidley	PARCEL	pargel
BAMBOO	Balboo	VIOLIN	viodin
SPIDER	Spimer	TATTOO	tartoo
JACKAL	Jankal	TEAPOT	teapit
BEETLE	Bretle	NEEDLE	nerdle
TENDON	Tandon	PILLAR	piltar
TOMATO	Torato	GUITAR	guitur
PEBBLE	Penble	DIESEL	dirsel
TURKEY	tulkey	NAPKIN	naskin
BANANA	banara	ENAMEL	eramel
CELERY	cedery	FABRIC	fablic
OYSTER	ogster	MOSAIC	motaic
GALAXY	ganaxy	PENCIL	puncil
AMAZON	alazon	JERSEY	jergey

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