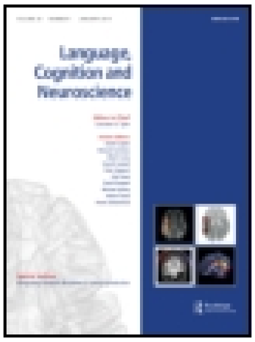

Language, Cognition and Neuroscience

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/plcp21

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LANGUAGE, COGNITION AND NEUROSCIENCE
https://doi.org/10.1080/23273798.2020.1849750

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Friend or foe? Flankers reverse the direction of orthographic neighbourhood effects

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ABSTRACT

Increasing the neighbourhood density of a word typically facilitates lexical decision responses and interferes in sentence reading. The Multiple Read-Out Model accounts for such variation by postulating that word responses in the lexical decision task can be made via two mechanisms – identifying the word or using the global lexical activity that it generates. Here, we asked whether adding unrelated flanking words to either side of the target would modulate the relative contribution of these two mechanisms. That is, do flankers promote the use of word identification processes that are more characteristic of sentence reading? In line with our hypothesis, in Experiment 1 flanker words increased the inhibitory influence of orthographic neighbours relative to single word presentation. In Experiment 2, flanker neighbourhood density did not affect lexical decisions to central targets. This pattern indicates that the mechanisms used to make a lexical decision can be modulated by a minimal "sentence-like" context.

ARTICLE HISTORY
Received 28 July 2020
Accepted 3 November 2020

KEYWORDS
Lexical decision task; orthographic neighbours; flankers task; lateral inhibition; Multiple Read-Out Model

Characterising the processes that underlie recognition of individual words has been at the forefront of research in psycholinguistics for decades. Within the word recognition literature, many studies have focused on the influence of orthographic neighbours. Orthographic neighbours are defined as words of the same length that differ by one letter (Coltheart et al., 1977). For example, the English word *share* has many neighbours (e.g. *shave*, *shark*) and is therefore said to come from a high-density (HD) neighbourhood. In contrast, *kayak* is said to come from a low-density (LD) neighbourhood because it is orthographically distinct. Across studies comparing processing of HD and LD words, evidence has accrued to confirm that neighbours are co-activated and affect processing of visual words (see, e.g. Andrews, 1997; Chen & Mirman, 2012; Perea & Rosa, 2000, for reviews). Interestingly, the behavioural manifestation of these co-activated neighbours disappears or even reverses depending on the task (e.g. Carreiras et al., 1997; Meade et al., 2019; Pollatsek et al., 1999). Fully understanding this complex relationship between neighbour interactions and task demands has implications for our understanding of the lexicon and how visual words are processed. Here, we take one step in that direction by further investigating how orthographic neighbourhood density affects performance in the lexical decision task (LDT).

Evidence in favour of neighbour co-activation has constrained models of visual word recognition, including the interactive-activation model (McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982). In this model, activated sublexical nodes spread activation forward to the lexical representations that contain them. Feedback from the activated lexical representations further boosts activation of the shared sublexical nodes. Together, these feedforward and feedback dynamics drive neighbour co-activation. To identify the target word amidst these alternatives, another central tenet of interactive-activation models is lateral inhibition. Bidirectional inhibitory links connect lexical representations, with the strength of inhibition governed by their relative activation. Data from sentence reading studies generally support this theory; increasing the number of neighbours that a word has boosts

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competition, yielding longer gaze durations for target and post-target regions (e.g. Dirix et al., 2017; Pollatsek et al., 1999). However, increasing the inhibitory potential of neighbours by increasing their frequency does not consistently lead to longer gaze durations (e.g. Perea & Pollatsek, 1998; Sears et al., 2006). Inhibitory effects of neighbourhood density have also been reported in single word paradigms, including progressive demasking (e.g. Carreiras et al., 1997). Overall, these interference effects are consistent with the lateral inhibitory links in the interactive-activation model.

One apparent exception to this pattern is the LDT, as many studies have demonstrated that increasing neighbourhood density can lead to faster word responses in that task (e.g. Andrews, 1989, 1992; Braun et al., 2006; Chwilla et al., 1995; Grainger & Jacobs, 1996; Holcomb et al., 2002; Meade et al., 2019; Perea et al., 1999).[1] To account for these different patterns of neighbourhood effects within the interactive-activation framework, Grainger and Jacobs proposed the Multiple Read-Out Model (MROM). They argued that a word response can be triggered in two ways. The M criterion relates to identification of a specific lexical item and approximates the processes engaged during sentence reading. The Sigma criterion relates to global lexical activity summed across the target word and its co-activated neighbours. To explain the facilitative effect of neighbourhood density in the LDT, Grainger and Jacobs proposed that the greater amount of global lexical activity generated by HD words compared with LD words gives rise to facilitatory effects of neighbourhood density via the Sigma response criterion. Furthermore, the relative use made of the Sigma and M criteria can vary depending on list context (e.g. Carreiras et al., 1997) and task demands (e.g. Grainger & Jacobs, 1996), hence accounting for variations in the size and direction of neighbourhood effects as a function of these factors. If neither the M nor the Sigma criteria have been reached by a certain time (the T criterion), then a "nonword" response is triggered. The T criterion can be adjusted based on the global lexical activity generated early during processing as well as task demands.

In the first experiment presented here, we asked if a more naturalistic context would change the way in which participants make lexical decisions to words. One paradigm that is arguably closer to normal reading is the flankers task, in which stimuli are placed to the left and right of a central target. Many studies have shown that lexical decisions to central targets are facilitated by orthographically related flankers (e.g. Dare & Shillcock, 2013; Grainger et al., 2014; Snell et al., 2018; Snell et al., 2018), mimicking the effects of orthographic relatedness in sentence reading (e.g. Angele et al., 2013; Dare & Shillcock, 2013; Snell, Vitu et al., 2017). There is also evidence to suggest that the distribution of spatial attention in the flankers task resembles that of normal reading (Snell & Grainger, 2018). If the flanker paradigm induces more natural reading behaviour, then adding flankers might encourage participants to make greater use of the M criterion for word responses.[2] To test this, we compared the effect of target word neighbourhood density on lexical decision responses across two contexts: targets presented alone (e.g. *ferme*) and flanked by an unrelated word (e.g. *atout ferme atout*). We predicted that the presence of a minimal "sentence-like" context would increase the inhibitory influence of neighbourhood density, and that we would therefore observe an interaction between neighbourhood density and flanker context.

Experiment 1

Methods

Participants

Data were collected from 28 native French speakers (20 female; mean age 22.71 years, *SD* 4.94 years).[3] Participants were volunteers who provided informed consent in accordance with the local institutional review board and received monetary compensation for their time.

Stimuli

Targets consisted of 120 French words and 120 pseudowords.[4] Half of the target stimuli in each condition came from HD neighbourhoods (at least 10 neighbours) and half came from LD neighbourhoods (fewer than four neighbours). HD words (mean 13.07, *SD* 3.15) had significantly more neighbours than LD words (mean 1.92, *SD* 1.09), $t(118) = 25.90$. However, lexical frequency was controlled between HD (mean 101.08, *SD* 115.11) and LD (mean 101.73, *SD* 148.55) words, $t(118) = .03$, $p = .980$, and the distribution of four- and five-letter words was identical (mean 4.27 letters, *SD* 0.45). Each pseudoword target was chosen to match a word target with respect to word length and number of neighbours.

Additionally, 60 French words were chosen as flankers. Each participant saw each flanker paired with the four target conditions. There was no orthographic or semantic overlap between the flanker and its targets. On average, the flanker words had 5.78 neighbours (*SD* 1.77) and a frequency of 37.03 (*SD* 58.75).

Procedure

The experiment consisted of a practice block with eight trials followed by two experimental blocks with 240 trials each. Target stimuli were presented with flankers in one block and alone in the other. Each target appeared once in each context in randomised order with the order of the two contexts counterbalanced across participants.

Each trial began with a blank screen for 500 ms followed by a centrally-presented target for 170 ms (see Figure 1). In the flanker block, the flanker word also appeared for 170 ms on either side of the target, separated by one space. This short duration has been used in previous studies (e.g. Declerck et al., 2018; Snell et al., 2018) to minimise saccades to the flankers. Participants categorised the target stimulus as either a word or a nonword by pressing the "!" or "w" key, respectively, on an AZERTY keyboard. Once a response was registered, or after 2000ms maximum, a dot that was green for correct responses and red for incorrect responses was displayed for 400 ms. The next trial began after this feedback.

Data analysis

On average, 8.1% of word target trials and 12.2% of pseudoword target trials were excluded from RT analyses due to incorrect responses or RTs more than three standard deviations away from the respective means.

The RT and error data were analysed using linear and logistic mixed-effects regression modelling, respectively (Baayen et al., 2008; Jaeger, 2008). Both participants and items were considered random factors with both fixed effects (i.e. Context [Flanker, Single Word] and Neighbourhood Density [HD, LD] using effect coding) and their interaction varying by all random factors (Barr et al., 2013). For this and all other models, we used the following strategy in case of a convergence or singularity issue with the fully randomised model (cf. Barr et al., 2013; Matuschek et al., 2017): We first excluded random effects for the item-specific random slopes, starting with the higher-order interactions. If the issue was still not resolved, then we moved on to the higher-order interactions of the participant-specific random slopes. Then we removed lower-order terms, again starting with the item-specific random slopes before moving on to the participant-specific random slopes. *T*- and *z*-values of 1.96 or more were deemed significant (Baayen, 2008).

Results

Mean RTs and percentage of errors for each condition are summarised in Table 1.

Word targets

The RT analysis for word target trials revealed a significant main effect of context (see Table 2), indicating slower RTs in the flanker context (581 ms) compared to the single word context (542 ms). The main effect of neighbourhood density was not significant for word targets. Crucially, however, there was a significant interaction between context and neighbourhood density indicating that the inhibitory effect of increasing neighbourhood density was larger in the flanker context (17 ms) than in the single word context (2 ms).

Closer inspection of the data revealed a modulatory role of block order. Recall that half of the participants saw the single word context first and half of them saw the flanker context first. An exploratory analysis showed a significant three-way interaction between block order, context, and neighbourhood density, $b = -32.77$, $SE = 10.93$, $t = -3.00$. The critical interaction between neighbourhood density and context was significant in the group of participants who saw the single word context first (flanker context: 21 ms; single word context: −9 ms), $b = -30.53$, $SE = 8.18$, $t = -3.73$, but not in the group of participants who saw the flanker context first (flanker context: 12 ms; single word context: 14 ms), $b = 2.02$, $SE = 9.25$, $t = 0.22$.

In contrast, there were no significant effects in the error analyses (see Table 3).

Pseudoword targets

As for the word targets, a significant main effect of context indicated that pseudoword targets elicited slower RTs in the flanker context (642 ms) relative to the single word context (612 ms; see Table 4). There was also a significant main effect of neighbourhood density such that HD pseudoword targets (644 ms) elicited slower responses than LD pseudoword targets (612 ms). In the error analysis, the only significant

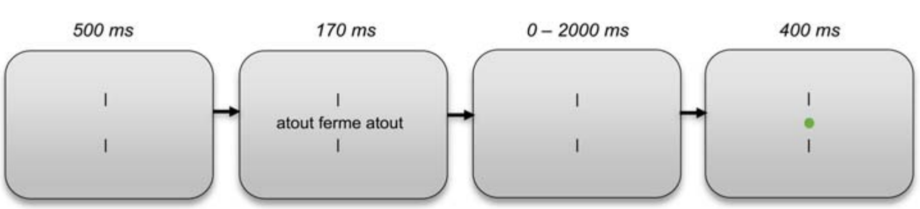

Figure 1. Overview of the trial structure. Targets (e.g., *ferme*) appeared with flankers (e.g. *atout*) in one half of the experimental list and without them in the other half. Visual proportions are not to scale.

Table 1. RTs in ms and percentage of errors for word and pseudoword target trials in Experiment 1 as a function of Neighbourhood (HD, LD) and Context (Flanker, Single Word). SE in parentheses.

	Target type	Neighbourhood Density	Flanker context	Single word context
RTs	Words	HD	589 (15)	543 (16)
		LD	572 (14)	541 (15)
	Pseudowords	HD	659 (18)	628 (19)
		LD	626 (18)	597 (16)
Percentage of Errors	Words	HD	7.7 (0.8)	7.4 (1.2)
		LD	6.5 (1.0)	6.0 (0.9)
	Pseudowords	HD	14.4 (1.9)	15.1 (2.8)
		LD	6.1 (1.7)	7.9 (2.4)

Table 2. *b*-, *t*-values, and standard errors of the reaction time analysis of word target trials in Experiment 1.

Factors	*b*-value	SE	*t*-value
Context	−39.28	9.52	−4.13
Neighbourhood Density	9.47	7.00	1.35
Context × Neighbourhood Density	−13.87	6.41	−2.16

Table 3. *b*-, *z*-values, and standard errors of the error analysis of word target trials in Experiment 1.

Factors	*b*-value	SE	*z*-value
Context	−0.15	0.14	−1.12
Neighbourhood Density	0.23	0.22	1.04
Context × Neighbourhood Density	0.06	0.20	0.29

Table 4. *b*-, *t*-values, and standard errors of the reaction time analysis of pseudoword target trials in Experiment 1.

Factors	*b*-value	SE	*t*-value
Context	−29.67	11.34	−2.62
Neighbourhood Density	35.06	9.47	3.70
Context × Neighbourhood Density	−0.45	6.18	−0.07

effect was a main effect of neighbourhood density such that HD pseudoword targets (14.8%) elicited more errors than LD pseudoword targets (7.0%; see Table 5).

Discussion

Overall, the interactions between context and neighbourhood from Experiment 1 are consistent with our hypothesis that the context in which words are presented changes the mechanism used to make lexical decisions to word targets. The minimal "sentence-like" context of flankers biases participants to identify target words (i.e. the M criterion in MROM) before making a response, which reverses the effect of neighbourhood density relative to when words are presented in isolation. Unexpectedly, this interaction was further influenced by block order, such that participants who saw the words in the flanker context first continued to use the M criterion. The results also support the hypothesised single criterion for "nonword" responses in MROM. Although HD pseudoword targets elicited slower and less accurate responses than LD pseudoword targets, the presence of flankers did not modulate the size of this effect. Crucially, and in line with the predictions of the MROM, the significant interaction found with word targets contrasts with the absence of an interaction with pseudoword targets.

Table 5. *b*-, *z*-values, and standard errors of the error analysis of pseudoword target trials in Experiment 1.

Factors	*b*-value	SE	*z*-value
Context	0.03	0.16	0.16
Neighbourhood Density	1.04	0.18	5.63
Context × Neighbourhood Density	−0.16	0.18	−0.86

Experiment 2

The results from Experiment 1 suggest that participants are biased toward individual word identification (i.e. the M criterion in MROM) when making lexical decisions to word targets in the flankers task. To provide further evidence for this conclusion, we compared lexical decision responses to targets paired with HD (e.g. *ferme atout ferme*) versus LD flankers (e.g. *chien atout chien*). If lexical decisions are based on the M criterion, then flanker neighbourhood density should have little to no influence on performance. In contrast, if lexical decisions are based on the Sigma criterion, then increasing global lexical activity by increasing the neighbourhood density of the flankers should facilitate word decisions. Either way, increasing global lexical activity should delay the T criterion and interfere with "nonword" decisions to pseudoword targets.

Methods

Participants

Data were collected from a separate group of 24 native French speakers (21 female; mean age 21.54 years, *SD* 2.47 years). Participants were volunteers who provided informed consent in accordance with the local institutional review board and received monetary compensation for their time.

Stimuli

To manipulate flanker neighbourhood density, we used the HD and LD French target words from Experiment 1 as flankers. Conversely, we used the 60 flankers from Experiment 1 as target words here. An additional 60 French-like pseudoword targets were added for the purposes of the lexical decision task. Pseudoword targets were chosen to have the same length and similar neighbourhood densities as the word targets. Each target was presented to each participant with an HD flanker and an LD flanker, both of which were orthographically unrelated (i.e. shared no letters).

Procedure

Participants saw eight practice trials followed by 240 experimental trials. Half of all trials were real words. The target structure was identical to the flanker context block of Experiment 1.

Data analysis

On average, 11.7% of word target trials and 12.6% of pseudoword target trials were excluded from RT analyses due to incorrect responses or RTs more than three standard deviations away from the overall mean for the respective condition. The analysis approach was the same as in Experiment 1 except that the only fixed effect was Flanker Neighbourhood Density [HD, LD].

Results

Mean RTs and error rates are presented in Table 6. There were no significant effects of flanker neighbourhood density on lexical decisions to the word targets, either in terms of RTs, $b = 1.09$, $SE = 4.75$, $t = 0.23$, or accuracy, $b = 0.33$, $SE = 0.23$, $z = 1.43$. Similarly, flanker neighbourhood density did not significantly affect lexical decisions to the pseudoword targets, either in terms of RTs, $b = -.52$, $SE = 4.91$, $t = -0.11$, or error rates, $b = -0.10$, $SE = 0.13$, $z = -0.79$.

Discussion

In Experiment 2, we manipulated the neighbourhood density of the flankers rather than the target words. The finding that flanker neighbourhood density had little effect on lexical decision responses provides further evidence for the conclusion that lexical decisions to word targets are based on word identification (i.e. the M criterion in MROM) rather than global lexical activity in the presence of flanker stimuli. We surmised that flanker neighbourhood density should contribute to overall global lexical activity and influence "nonword" responses via the T criterion. The finding that flanker neighbourhood density did not affect responses to pseudoword targets suggests that flanker neighbours were not in fact influencing the amount of global lexical activity generated by central targets. We discuss the consequences of this finding below.

Table 6. RTs in ms and percentage of errors for word and pseudoword target trials in Experiment 2 as a function of Flanker Neighbourhood (HD, LD). SE in parentheses.

Target type	Flanker Neighbourhood Density	RTs	Percentage of errors
Words	HD	592 (12)	9.9 (1.3)
	LD	593 (12)	11.3 (1.6)
Pseudowords	HD	664 (17)	11.6 (1.6)
	LD	663 (17)	10.8 (1.5)

General discussion

The goal of the present study was to determine if the presence of a minimal "sentence-like" context could change the way that lexical decisions are made. In Experiment 1, we compared the effect of neighbourhood density on LDT responses to the same French targets presented alone (e.g. *ferme*) versus flanked by an unrelated French word (e.g. *atout ferme atout*). In line with our predictions, we found that neighbourhood effects were modulated by flanker context such that the inhibitory effect of neighbourhood density (i.e. slower responses for HD target words compared to LD target words) was greater in the presence of flanker words. This result confirms that the minimal context of two flanking words is sufficient to encourage greater use of word identification processes in the LDT (i.e. via the M criterion in MROM) and to induce the neighbourhood effect that is typically observed in sentence reading (e.g. Dirix et al., 2017; Pollatsek et al., 1999). In contrast, the size of the neighbourhood density effect remained constant across conditions for pseudoword targets, indicative of a single response mechanism. This contrast between the effects found with word targets (an impact of flanker context on the neighbourhood effects) and pseudoword targets (no impact of flanker context on the neighbourhood effects) is not only a striking finding, but also a theoretically important one, given that it is exactly this pattern that was predicted by the MROM.

The order of presentation of the single word and flanker context blocks further impacted the pattern for word targets, with the crucial interaction only being significant when participants first received the single word block. The absence of a significant interaction when participants first saw the flanker context block was due to an increase in the inhibitory effect of neighbourhood density in the subsequent single word block. We suspect that this is a form of spill-over effect, with the impact of flanker context continuing to have an influence in the following block of trials without flankers. This would imply that the way in which lexical decisions are made is influenced not only by the way that the words are presented at any given point in time, but also by prior experience (see also Carreiras et al., 1997).

The proposal that lexical decisions in the flanker paradigm are made using word identification instead of global lexical activity is supported by previous findings. For example, there is evidence to suggest that the lexical status of flankers (i.e. words vs. pseudowords/nonwords) does not influence LDT responses to target words (Declerck et al., 2018). Given that information relevant for word decisions is pooled across target and flanker stimuli (Snell et al., 2018; Snell, Meeter, et al., 2017), accounts of lexical decision that apply a single decision criterion (i.e. accumulated evidence in favour of a word response; Dufau et al., 2012; Ratcliff et al., 2004) must predict effects of flanker lexicality.[5] Only a multiple response strategy model, such as MROM, can account for the absence of flanker lexicality effects. The presence of flankers encourages participants to make decisions based on word identification processes, which are immune to the lexicality of unrelated flanker stimuli.

Related to this issue is the finding in Experiment 2 that the neighbourhood density of flankers did not affect lexical decisions to word or to pseudoword targets. Experiment 2 was initially designed as a further test of our main prediction, that global lexical activity is not used to respond to words in the presence of flanking stimuli. When only considering the word targets, the results of Experiment 2 are indeed in line with this prediction. However, the fact that flanker neighbourhood density did not affect responses to pseudoword targets points to an alternative interpretation of the results of that experiment. That is, that flanker neighbourhood density does not significantly modulate the global lexical activity generated by target and flanker stimuli when these are orthographically unrelated. This finding fits well with the spatial pooling account of effects of target-flanker orthographic relatedness proposed by Grainger et al. (2014). According to this account, flanker neighbourhood density can only affect target processing by influencing the activation of neighbours that are already activated by the target. When flankers and targets are orthographically unrelated, as was the case in the present study, then there can be no influence of flanker neighbourhood density.

Taken together, we have demonstrated that the direction of neighbourhood effects in the LDT can be modulated by the context in which the words appear and by prior experience. These effects are informative with respect to how participants making their “word” responses. The mere presence of unrelated flanker words biased them to rely on word identification rather than global lexical activity. However, the neighbourhood density of the unrelated flankers did not significantly modulate their impact on target processing. Finally, given that similar patterns were observed in the flanker paradigm here as are typically observed during sentence reading, the flanker paradigm might provide a more naturalistic context in which to investigate word recognition.

Notes

1. Other studies have failed to replicate this facilitatory influence of neighbourhood density in the lexical decision task (e.g. Carreiras et al., 1997).
2. This hypothesis and all methods for this experiment were pre-registered in the Open Science Framework repository (https://osf.io/mt5zb) prior to double-blind data collection. Exploratory analyses that were not pre-registered are indicated as such. Pseudoword analyses were also conducted and included in response to a request from an anonymous reviewer.
3. A power analysis for data with random participants and items was used to determine the number of participants (Green and MacLeod, 2016). As suggested by Brysbaert and Stevens (2018), we ran 200 Monte Carlo simulations using the SIMR package in R on the data reported by Meade et al. (2019). The results showed that power was 86% to observe the main effect of neighbourhood density with 28 participants. The present study is the first in which the interaction between neighbourhood density and flanker context is investigated, so there was no dataset available to directly estimate power for the interaction.
4. All materials, data, and analysis scripts for both experiments have been made publicly available (https://osf.io/tjm53).
5. We also note that such single mechanism accounts of lexical decision cannot account for the present findings. See Grainger (2018) for a proposal that integrates an accumulative word evidence mechanism within the framework of MROM.

Acknowledgements

This project was funded by European Research Council Grant ERC 742141. GM was supported by Graduate Research Fellowship 2016196208 from the National Science Foundation and an international collaboration travel award from Women in Cognitive Science.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This project was funded by European Research Council Grant ERC 742141. GM was supported by Graduate Research Fellowship 2016196208 from the National Science Foundation and an international collaboration travel award from Women in Cognitive Science.

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