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Tests of a model of multi-word reading: Effects of parafoveal flanking letters on foveal word recognition

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ABSTRACT

We used the "flanking letters lexical decision" paradigm of Dare and Shillcock (2013) in order to test a model of multi-word reading. In the model, multiple words (on fixation, and to the left and right of fixation) are processed in parallel by a bank of location-specific letter detectors. These letter detectors feed information forward to a "bag of bigrams" that represents location-invariant sublexical orthographic information for all words processed in parallel. Bigrams are only formed within words (i.e., between spaces) but activate all compatible word representations. The model accounts for a finding reported by Dare and Shillcock (2013): Word recognition is facilitated when flanking letter pairs are present in the target (e.g. RO ROCK CK) compared with different letter flankers (ST ROCK EN), but independently of the position of the flanking bigrams (e.g., CK ROCK RO). In the present study we replicate this key finding and show that, as predicted by the model, although bigram position does not matter, within-bigram letter position does. Word recognition is harder when the position of letters within bigram flankers is reversed (e.g., OR ROCK KC/KC ROCK OR), but these conditions still facilitate with respect to a different letter flanker condition.

1. Introduction

In a recent study, Dare and Shillcock (2013) reported what we believe to be a key finding for reading research. This finding was obtained using a novel paradigm, the "flanking-letters lexical-decision" paradigm, where target words and nonwords on which subjects make lexical decisions are flanked by letter pairs located to the left and right of the target and separated from targets by a single space. Dare and Shillcock (2013) found that when flanking letters were present in the target, lexical decisions were facilitated for word stimuli compared with the condition where flanking letters were not present in the target. Most important is that this flanking-letter effect did not depend on the left–right ordering of the letter pairs such that response times (RTs) were the same to the target word "ROCK" when flanked by "RO" to the left and "CK" to the right and when flanked by "CK" to the left and "RO" to the right (0 ms difference between these two conditions for both high-frequency and low-frequency words, see Fig. 3a).

This rather counterintuitive finding fits well with the theoretical framework for multiple-word processing proposed by Mozer (1987) and adapted in the more recent work of Grainger and Van Heuven (2003). Here we describe how a straightforward extension of the Grainger and van Heuven model, that retains many of the key properties of Mozer's Blirnet model, provides a simple account of Dare and Shillcock's results. An informal presentation of the model suffices at present for describing how it accounts for these findings, and how it generates predictions with respect to the new conditions to be tested in the present study. The architecture of the model is shown in Fig. 1. The first layer of the model performs parallel independent letter processing via a horizontally aligned bank of location-specific letter detectors. Two main factors determine activity at this level of processing: acuity and crowding. Bottom-up input to letter detectors drops linearly with increasing eccentricity, but letters at the outer positions of words benefit from reduced crowding. This leads to the typical W-shaped serial position function for letter identification accuracy with centrally fixated strings (e.g., Tydgat & Grainger, 2009). The second layer of the model is a "bag of bigrams" representing an unordered set of ordered letter combinations. Following Grainger and Van Heuven (2003) we use an open-bigram scheme such that the letter combinations include contiguous and non-contiguous sequences of two letters. Following Hannagan and Grainger (2012) we include the space character (#) along with the 26 letters of the alphabet when generating bigrams, such that information about single letters is also encoded.[1] The third and final layer of the model is a set of whole-word orthographic representations that relays information onto semantic representations.

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[1] As noted by Hannagan and Grainger (2012), the addition of a space character in a bigram coding scheme corresponds to "both edges" coding (Fischer-Baum, McCloskey, & Rapp, 2010), provided that information about the distance between the space and the letter is also available. This enables an implementation of both coarse-grained and fine-grained orthographic codes, as defined by Grainger and Ziegler (2011), within a single representational scheme.

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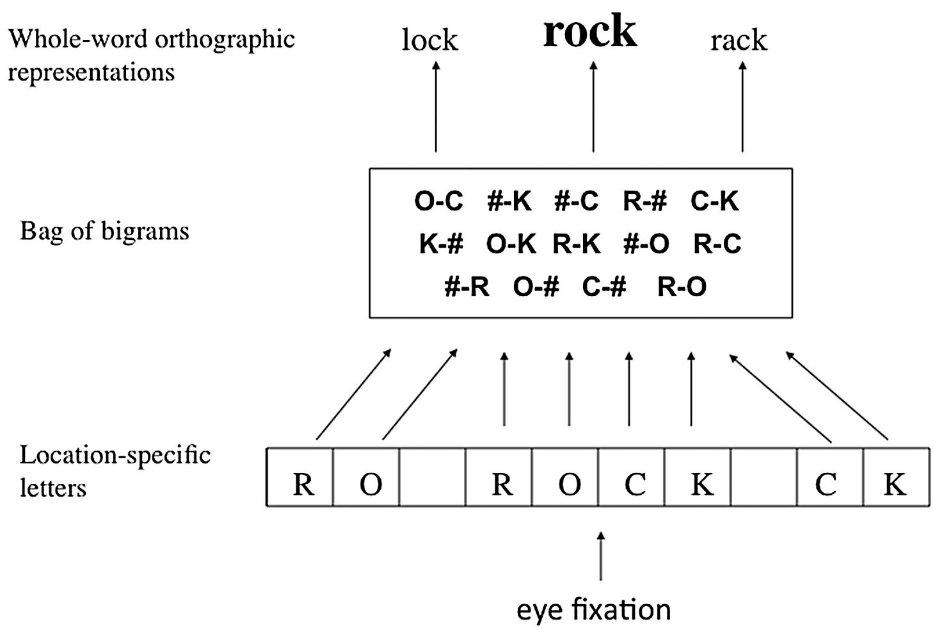

Fig. 1. Extension of Grainger and Van Heuven's (2003) model of orthographic processing to the case of multiple words (strings separated by spaces). Location-specific letter detectors operate in parallel across multiple words, signaling the evidence that a given letter identity or inter-word space is present at a given location relative to eye fixation. This information is used to activate ordered pairs of contiguous and non-contiguous character combinations (26 letters augmented with the space character—#) stored as an unordered set of open-bigrams (a bag of bigrams). Bigrams then activate whole-word orthographic representations for unique word identification (winner-take-all).

During fixation within a given word, location-specific letter detectors process visual information about the fixated word as well as information to the left and right of that word, within the limits imposed by acuity, crowding, and spatial attention (e.g., Marzouki, Meeter, & Grainger, 2013). All activated letter detectors send activation on to all compatible bigram representations in the bag of bigrams. The only additional constraint within this single-channel approach to multiple-word reading is that bigrams are only formed within words and not between words. That is, when reading the phrase "gray mouse", bigrams "g-r" and "g-y" but not "y-m" are activated. This constraint is essential for implementing parallel processing of sublexical orthographic information across several words while limiting the generation of illusory words formed by combinations of letters from different words. It points to a key role for inter-word spaces in orthographic processing in general, as already revealed in prior research (e.g., Morris, Rayner, & Pollatsek, 1990; Rayner, Fischer, & Pollatsek, 1998; Winskel, Radach, & Lukaneeyanawin, 2009).

Once location-specific letter detectors begin to activate bigram representations, activity in these bigram detectors is then fed-forward to whole-word orthographic representations, which compete with each other for unique word identification via lateral inhibition. Once a word is identified, activity in the corresponding whole-word orthographic representation is suppressed in order to remove interference during processing of the subsequently fixated word. This model therefore enables parallel processing of orthographic information spanning several words while ensuring that only one word is identified at a time.

The model accounts for the results of Dare and Shillcock (2013) because flanking letter pairs will generate activation in bigram representations independently of whether they appear to the left or to the right of fixation. The model predicts, however, that reversing the order of letters within the flanking letter pairs (e.g., 21 1234 43)[2] should make target word recognition harder than when the order is not reversed (12 1234 34). Priming will, however, still arise in the reversed letter condition relative to a different letter condition (dd 1234 dd) because of the "single letter" bigrams (bigrams formed by combining the space character and a letter). The model therefore predicts no difference between conditions 12 1234 34 and 34 1234 12, but both should facilitate target word recognition relative to conditions 21 1234 43 and 43 1234 21, which in turn should facilitate target word recognition relative to the different letter condition dd 1234 dd.

In sum, we will use the flanking-letters lexical-decision paradigm in order to i) replicate the key finding of Dare and Shillcock (2013), and ii) test a key prediction of our model of multiple-word reading. The flanking-letter conditions to be tested are:

12 1234 34; 34 1234 12; 21 1234 43; 43 1234 21; dd 1234 dd.

We use these conditions to provide pairwise estimates of flanking letter effects relative to a different-letter condition, plus an analysis of letter order and bigram order in a 2 × 2 factorial design (without the different-letter condition). We expect all conditions where flankers contain letters in the target to facilitate word recognition compared with different-letter flankers. We also expect to replicate the absence of an effect of bigram order reported by Dare and Shillcock, such that conditions 12 1234 34 and 21 1234 43 are the same as conditions 34 1234 12 and 43 1234 21. We also expect to observe an effect of letter order such that conditions 12 1234 34 and 34 1234 12 will improve target word recognition compared with conditions 21 1234 43 and 43 1234 21.

2. Method

2.1. Participants and apparatus

Twenty students from Aix-Marseille University participated in the experiment, and received €3 or course credit for their participation. All participants reported normal or corrected vision and were native French speakers. The experiment was conducted on a 19″ TFT monitor with a resolution of 1280 × 1024 pixels and a refresh rate of 60 Hz. Stimulus presentation was controlled using OpenSesame (Mathôt, Schreij, & Theeuwes, 2012).

[2] Following the notation used to describe experimental conditions in research on orthographic priming, flanking letter conditions are described by using numbers to indicate the position of a flanking letter in the target when the letter is present in the target, and using the letter "d" (different letter) otherwise.

2.2. Stimulus selection

Words were selected from the Lexique database (New, Pallier, Brysbaert, & Ferrand, 2004) using a semi-automated procedure. An initial selection was made based on the following criteria: Four letter long; Lexical frequency of ten-per-million or more (based on the freqlivres entry in Lexique); No accents or special characters; No character repetitions; Flanker permutations were not words themselves (for example, 3412, 2143, and 4321 should not be words, given word 1234). For each selected word, a matching non-word was generated with Wuggy (Keuleers & Brysbaert, 2010) using the Orthographic French lexicon (other settings per default). After manually removing undesirable entries from the resulting list of word/non-word pairs, the 100 most frequent words and their corresponding non-words were selected ($M = 639$ occurrences per million, range 59–8296).

2.3. Design

The paradigm was modeled after Experiment 1 from Dare and Shillcock (2013). Fig. 2 summarizes the procedure. Each trial started with two bright vertical fixation bars above and below the center of an otherwise dark screen. After 1000 ms, the target was presented (a word or non-word), flanked by two letters on each side, in 18 pt Courier New font. The spacing between target and flankers corresponded to a single character. After 150 ms, the display was blanked. Participants indicated as quickly and accurately as possible whether the target was a word or a non-word, by pressing the left or right button on a gamepad. The response rule was balanced across participants. After a correct response, a smiley face was presented for 250 ms. After an incorrect response, a frowney face was presented for 1000 ms, accompanied by a reminder of the instructions.

There were five flanker conditions. In the "different" condition, the target was flanked by letters (in their original order) taken from a different string, which was randomly selected with replacement from all strings in the same category (word/non-word) that shared no letters with the target. In the remaining flanker conditions, the flanking letters were taken from the target word. These four conditions were formed by crossing Bigram Order (same vs. switch) and Letter Order (same vs. switch). Illustrated by example, the "bigram-same/letter-same" condition corresponds to "12 1234 34"; the "bigram-switch/letter-same" condition corresponds to "34 1234 12"; the "bigram-same/letter-switch" condition corresponds to "21 1234 43"; the "bigram-switch/letter-switch" corresponds to "43 1234 21". We used a reduced-Latin-square design, so that each target appeared in only one condition for one participant, but in all conditions across all participants. Category (word; non-word) and flanker condition were randomly mixed across blocks. The experiment consisted of 200 trials.

3. Results

Trials were discarded when response times (RTs) were more than 2.5 *SD* above or below the participant's mean RT (2.0%). After filtering, the mean correct RT was 540 ms, and the accuracy was 88%. As dependent measure we used Adjusted RT (otherwise known as the inverse efficiency score, *IES*; Townsend & Ashby, 1983), which corresponds to the mean correct RT divided by accuracy (probability correct), calculated per condition and per participant (or per item in the analyses by item). This measure has the benefit of not being susceptible to speed-accuracy trade-offs. For completeness, the (unadjusted) mean correct RTs and accuracy scores are provided in Table 1. Following the advice of Townsend and Ashby (1983) we also checked that mean RT and percentage correct correlated highly across the 10 conditions we tested: $r = -0.84$, $p = 0.002$.

Table 1
Overview of results showing condition means for adjusted RT (mean correct RT/accuracy), mean correct RT (ms), and accuracy (proportion correct).

Flanker condition		Words			Non-words		
Bigram	Letter	Adj. RT	RT	Accuracy	Adj. RT	RT	Accuracy
Same	Same	544	504	.93	672	559	.85
Same	Switch	585	514	.88	635	553	.88
Switch	Same	555	506	.91	672	555	.84
Switch	Switch	586	518	.89	648	562	.86
Different Letter		623	530	.86	668	561	.85

Our analyses focused on two questions. Firstly, did the same-word flankers facilitate lexical-decision times relative to different-word flankers, as reported by Dare and Shillcock (2013)? Secondly, was there an effect of bigram order and/or letter order on lexical-decision responses to word targets? The following analyses are based on word trials only. To investigate the overall facilitation caused by flankers sharing letters with targets, we performed four two-sided paired-samples *t*-tests, which revealed facilitation in all four shared-letter conditions relative to the different-letter flanker condition: "bigram-same/letter-same": $t(19) = 5.8$, $p < .01$; "bigram-same/letter-switch": $t(19) = 3.0$, $p = .01$; "bigram-switch/letter-same": $t(19) = 4.8$, $p < .01$; "bigram-switch/letter-switch": $t(19) = 2.2$, $p = .04$.

To investigate the effect of bigram and letter order, we performed a Repeated Measures Analysis of Variance (ANOVA) using Bigram Order and Letter Order as within-subject factors, and Adjusted RT as dependent measure (see Fig. 3b). Crucially, this analysis revealed an effect of Letter Order ($F(1,19) = 14.8$, $p < .01$), but no effect of Bigram Order ($F(1,19) = 1.0$, ns), and no interaction ($F(1,19) = 0.1$, ns). The same analysis conducted within-items yielded the same results: an effect of Letter Order ($F(1,99) = 6.5$, $p = .01$), but no effect of Bigram Order ($F(1,99) < 0.1$, ns), and no interaction ($F(1,99) < 0.1$, ns).

The same analyses on non-word trials yielded no significant effects. Four two-sided paired-samples *t*-tests revealed no facilitation in any shared-letter flanker condition, relative to the different-letter flanker condition (all $p > .5$), and the ANOVA revealed no effect of Bigram Order ($F(1,19) = 0.4$, ns), no effect of Letter Order ($F(1,19) = 1.8$, ns), and no interaction ($F(1,19) = 0.8$, ns). The same analysis conducted within-items yielded the same results: no effect of Bigram Order ($F(1,99) = 0.1$, ns), no effect of Letter Order ($F(1,99) = 0.5$, ns), and no interaction ($F(1,99) < 0.1$, ns).

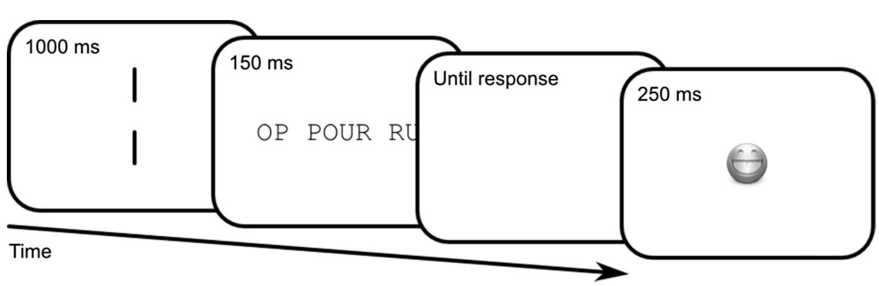

Fig. 2. Schematic example trial in the word/bigram-order-same/letter-order-switch condition (see text for stimulus details). Each trial started with central fixation bars, followed by a briefly presented target stimulus. The target stimulus was flanked on each side by a bigram. The smiley face was shown only after a correct response.

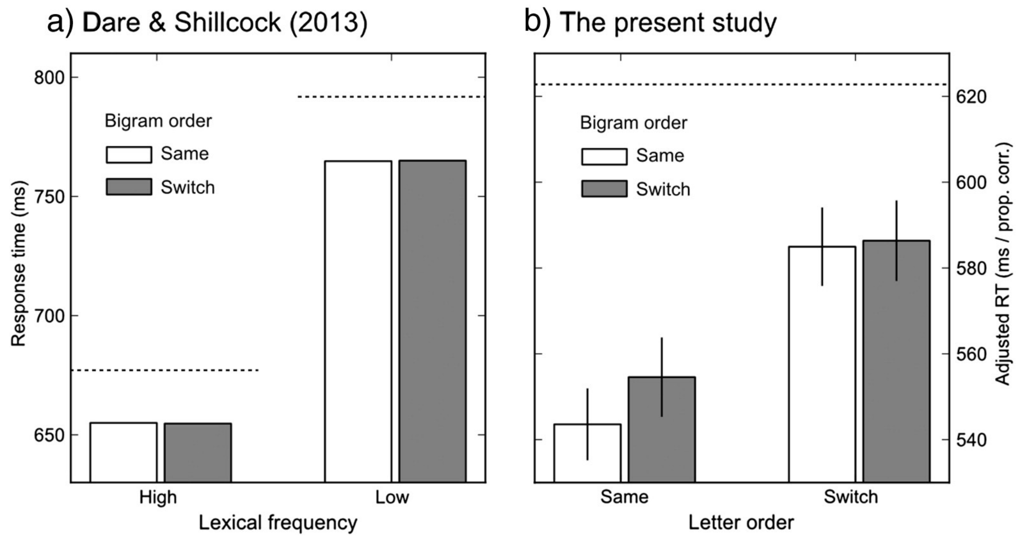

Fig. 3. a) Results of Dare and Shillcock (2013) showing the absence of an effect of bigram order for both high-frequency and low-frequency words in their study. b) Results of the present experiment replicating the absence of an effect of bigram order and revealing an effect of letter order. Dashed lines show performance in the unrelated flanker conditions. Error bars are within-subject standard errors (Cousineau, 2005).

4. Discussion

A straightforward extension of Grainger and Van Heuven's (2003) model of orthographic processing, inspired by the seminal work of Mozer (1987), provides an explanation for the recent findings of Dare and Shillcock (2013). In their study, Dare and Shillcock introduced a new paradigm, the flanking-letters lexical-decision task, in which target words and nonwords are flanked to the right and to the left by pairs of letters, separated by a space from the target. They found that lexical-decision responses to word targets were facilitated when flanking letters were present in the target compared with flanking letters that were not part of the target. This flanking-letter facilitation was found for flanking-letter pairs (bigrams) that respected the order of letters in the target word, but independently of the position of the bigram. Thus, recognition of the target word ROCK was facilitated to exactly the same extent by flankers RO ROCK CK and by flankers CK ROCK RO, compared with the different-flanker condition (LE ROCK SH). Our model accounts for this important finding via parallel letter-identification processes that feed information into an unordered set of ordered letter-combination representations (bag of bigrams).

In the present study we replicated this key finding of Dare and Shillcock (2013) and tested a new prediction of our model. The prediction was that although bigram order does not matter, letter order does. Thus, for the same example target word ROCK, we predicted that conditions OR ROCK KC and KC ROCK OR should hinder target word recognition compared with the flanker conditions where letter order is respected, as described above. The results of our experiment confirmed this prediction, revealing a significant effect of letter order and no effect of bigram order. The reversed letter flankers did nevertheless facilitate word recognition compared with the different-letter flanker condition. Our model accounts for this via "single letter" bigrams formed of a combination of a space character and a letter. Thus the flanking letters OR will activate bigrams #O, #R, O#, and R#, all of which are part of the representation of the word ROCK.[3]

[3] The size of the advantage for maintaining letter order will depend on the relative weight assigned to these "single letter" bigrams among the complete set of open-bigrams. We are currently examining this possibility in on-going computational work by training networks to map bigram representations onto whole-word orthographic representations using the delta learning rule.

Davis and Bowers (2004) had already anticipated our proposed extension of the Grainger and Van Heuven (2003) model, when discussing possible accounts of the pattern of letter-migration effects they observed in their study. Indeed, letter-migration errors were one of the key empirical findings behind the development of Mozer's (1987) model of multiple-word reading. In a typical letter migration experiment, subjects fixate a central fixation point and are briefly presented with two words, one to the left and the other to the right of fixation (e.g., STEP + SHOP), and are asked to report the identity of the two words. Of interest are the errors in subjects' reports, such as the word STOP from the above example (McClelland & Mozer, 1986). Davis and Bowers (2004) made a key contribution to the letter-migration literature by showing that such migration errors did not always respect the absolute position of letters within words, whenever this was possible. So, for example, when subjects saw STEP + SOAP, the word STOP was also produced in error, with a statistically indistinguishable proportion to the STEP + SHOP condition. As noted by Davis and Bowers (2004), an open-bigram model of orthographic processing readily accounts for these findings (but see Fischer-Baum, Charny, & McCloskey, 2011, for more recent results in favor of a both-edges coding scheme).

How might alternative models of orthographic processing be adapted to the case of multiple word reading, and might they be able to accommodate the results obtained with the flanking letters lexical decision task? Noisy slot-coding models (Gómez, Ratcliff, & Perea, 2008; Norris, 2006) encode orthographic information using position-specific letter detectors that detect the presence of a given letter identity at a given position in a word. Because these letter detectors are word-centered and location-invariant, parallel processing of multiple words can only be achieved by having separate channels for each word such that there is a detector for position 1 in word 1 and a separate detector for position 1 in word 2. This class of models therefore incorrectly predicts no effect of orthographic overlap in the flanking letters lexical decision paradigm. Models that use beginning-to-end activation gradients in order to encode letter order (Davis, 2010; Whitney, 2001) might also have difficulty in accounting for results obtained with the flanking letters lexical decision paradigm. Both Davis (2010) spatial coding model (SCM) and Whitney's (2001) SERIOL model require sequential beginning-to-end processing of the printed word in order to initiate the assignment of positions to letter identities (by a spatial code in the SCM, and via open-bigrams in SERIOL). This sequential process can only operate one word at a time, otherwise letter positions would be incorrectly assigned to a single orthographic object corresponding to word combinations. Therefore, in order to achieve parallel processing of multiple words, these models would require the simultaneous operation of sequential processing mechanisms.

Our model of multiple-word processing was developed as the simplest possible extension of the Grainger and Van Heuven (2003) model of orthographic processing during single-word recognition to the case of multiple word processing. It immediately generated some very precise predictions with respect to effects of parafoveal stimuli during processing of the fixated foveal word. One obvious prediction was that having the same word in the parafovea as the fovea should facilitate processing of the fixated word. Thus, in a sentence reading paradigm using the boundary technique (Rayner, 1975) so that subjects are unaware of the experimental manipulation, subjects reading “the store had a coat/coat …”, where the 2nd occurrence of “coat” is replaced by the word “sale” when the eyes leave the 1st occurrence of “coat”, should be faster at reading “coat” in this context compared with a sentence like “the store had a coat/milk …” (with “milk” being replaced by “sale” when the eyes leave “coat”). This prediction was confirmed in two recent eye-movement studies (Angele, Tran, & Rayner, 2013; Dare & Shillcock, 2013). Furthermore, Dare and Shillcock (2013) also showed facilitation from parafoveal nonword stimuli formed by transposing two letters of the foveal word (e.g., the store had a coat/caot …) compared with a double-substitution control condition (e.g., the store had a coat/ceit …). These results clearly suggest that orthographic information extracted in parallel from the fovea and the parafovea collectively influences the process of foveal word recognition, hence extending prior observations of parafoveal-on-foveal effects during reading (e.g., Kennedy & Pynte, 2005; Kliegl, Nuthmann, & Engbert, 2006; Vitu, Brysbaert, & Lancelin, 2004). Our model describes possible underlying mechanisms enabling the integration of foveal and parafoveal information that might form the basis of such influences.

In a daring paradigmatic shift, Dare and Shillcock (2013) introduced a new paradigm for research on word recognition and reading that holds much promise with respect to developing our understanding of how information from the fixated word and neighboring words are processed in parallel and conjointly influence foveal word recognition. The scope of exploitation of this paradigm is vast, and we expect it to generate a large amount of research in the coming years. Obvious extensions of the paradigm include varying the number of flanking letters, the lexical status of the recombination of flanking letters as well as their orthographic relation to targets (e.g., BL BLUR UE). In the present study we replicated the key findings of Dare and Shillcock, and tested and confirmed one clear prediction derived from our model of multiple-word reading. Apart from generating predictions to be tested in future research using the flanking-letters lexical-decision paradigm, the model also generates clear predictions with respect to the interaction of foveal and parafoveal information when reading ordinary text. Indeed the flanking-letters lexical-decision paradigm might well provide an important further step forward toward bridging the gap between research on single-word reading using button-press response measures and research on word-in-sentence reading using eye-movement recordings.

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Appendix A. List of target words and flankers

Target	Condition				
	12 1234 34	21 1234 43	34 1234 12	43 1234 21	dd 1234 dd
aime	ai aime me	ia aime em	me aime ai	em aime ia	po aime ur
avec	av avec ec	va avec ce	ec avec av	ce avec va	nu avec it
avis	av avis is	va avis si	is avis av	si avis va	tu avis er
bien	bi bien en	ib bien ne	en bien bi	ne bien ib	tr bien ou
bleu	bl bleu eu	lb bleu ue	eu bleu bl	ue bleu lb	ho bleu rs
bois	bo bois is	ob bois si	is bois bo	si bois ob	de bois ux
bord	bo bord rd	ob bord dr	rd bord bo	dr bord ob	pl bord us
bout	bo bout ut	ob bout tu	ut bout bo	tu bout ob	da bout ns
bras	br bras as	rb bras sa	as bras br	sa bras rb	nu bras it
camp	ca camp mp	ac camp pm	mp camp ca	pm camp ac	vi camp te
cent	ce cent nt	ec cent tn	nt cent ce	tn cent ec	av cent is
ceux	ce ceux ux	ec ceux xu	ux ceux ce	xu ceux ec	ma ceux in
chat	ch chat at	hc chat ta	at chat ch	ta chat hc	no chat rd
chef	ch chef ef	hc chef fe	ef chef ch	fe chef hc	nu chef it
cher	ch cher er	hc cher re	er cher ch	re cher hc	fo cher nd
chez	ch chez ez	hc chez ze	ez chez ch	ze chez hc	bo chez rd
ciel	ci ciel el	ic ciel le	el ciel ci	le ciel ic	pa ciel ys
cinq	ci cinq nq	ic cinq qn	nq cinq ci	qn cinq ic	lo cinq rs
coin	co coin in	oc coin ni	in coin co	ni coin oc	da coin me
coup	co coup up	oc coup pu	up coup co	pu coup oc	la coup it
cuir	cu cuir ir	uc cuir ri	ir cuir cu	ri cuir uc	pa cuir ys
dame	da dame me	ad dame em	me dame da	em dame ad	fi dame ls
dans	da dans ns	ad dans sn	ns dans da	sn dans ad	oe dans il
deux	de deux ux	ed deux xu	ux deux de	xu deux ed	mo deux rt
dieu	di dieu eu	id dieu ue	eu dieu di	ue dieu id	gr dieu os
dire	di dire re	id dire er	re dire di	er dire id	ca dire mp
donc	do donc nc	od donc cn	nc donc do	cn donc od	fi donc ls
dont	do dont nt	od dont tn	nt dont do	tn dont od	ch dont ez
face	fa face ce	af face ec	ce face fa	ec face af	mo face is
faim	fa faim im	af faim mi	im faim fa	mi faim af	pl faim us
fait	fa fait it	af fait ti	it fait fa	ti fait af	bo fait rd
faux	fa faux ux	af faux xu	ux faux fa	xu faux af	ve faux rt
fils	fi fils ls	if fils sl	ls fils fi	sl fils if	ch fils at
fois	fo fois is	of fois si	is fois fo	si fois of	tu fois er
fond	fo fond nd	of fond dn	nd fond fo	dn fond of	gr fond is
fort	fo fort rt	of fort tr	rt fort fo	tr fort of	pi fort ed
gare	ga gare re	ag gare er	re gare ga	er gare ag	bo gare ut
gens	ge gens ns	eg gens sn	ns gens ge	sn gens eg	hu gens it
gris	gr gris is	rg gris si	is gris gr	si gris rg	ce gris ux
gros	gr gros os	rg gros so	os gros gr	so gros rg	vi gros de
haut	ha haut ut	ah haut tu	ut haut ha	tu haut ah	co haut in
hier	hi hier er	ih hier re	er hier hi	re hier ih	po hier nt
hors	ho hors rs	oh hors sr	rs hors ho	sr hors oh	da hors me
huit	hu huit it	uh huit ti	it huit hu	ti huit uh	fo huit nd
joie	jo joie ie	oj joie ei	ie joie jo	ei joie oj	pa joie rt
jour	jo jour ur	oj jour ru	ur jour jo	ru jour oj	ch jour ef
lait	la lait it	al lait ti	it lait la	ti lait al	jo lait ur
leur	le leur ur	el leur ru	ur leur le	ru leur el	fa leur im
lieu	li lieu eu	il lieu ue	eu lieu li	ue lieu il	pa lieu rt
lire	li lire re	il lire er	re lire li	er lire il	co lire up
loin	lo loin in	ol loin ni	in loin lo	ni loin ol	pa loin rt
long	lo long ng	ol long gn	ng long lo	gn long ol	fa long im
lors	lo lors rs	ol lors sr	rs lors lo	sr lors ol	fa lors ce
lune	lu lune ne	ul lune en	ne lune lu	en lune ul	bo lune is
main	ma main in	am main ni	in main ma	ni main am	to main us
mois	mo mois is	om mois si	is mois mo	si mois om	tu mois er
mort	mo mort rt	om mort tr	rt mort mo	tr mort om	av mort is
noir	no noir ir	on noir ri	ir noir no	ri noir on	fa noir ux
nord	no nord rd	on nord dr	rd nord no	dr nord on	se nord pt
nous	no nous us	on nous su	us nous no	su nous on	ch nous ez
nuit	nu nuit it	un nuit ti	it nuit nu	ti nuit un	pa nuit ys
oeil	oe oeil il	eo oeil li	il oeil oe	li oeil eo	ch oeil at
paix	pa paix ix	ap paix xi	ix paix pa	xi paix ap	ve paix nt
part	pa part rt	ap part tr	rt part pa	tr part ap	ci part el
pays	pa pays ys	ap pays sy	ys pays pa	sy pays ap	ro pays be
peau	pe peau au	ep peau ua	au peau pe	ua peau ep	gr peau is
peur	pe peur ur	ep peur ru	ur peur pe	ru peur ep	co peur in
pied	pi pied ed	ip pied de	ed pied pi	de pied ip	sa pied ng
plan	pl plan an	lp plan na	an plan pl	na plan lp	ve plan rt
plus	pl plus us	lp plus su	us plus pl	su plus lp	vi plus te
pont	po pont nt	op pont tn	nt pont po	tn pont op	fa pont ce
pour	po pour ur	op pour ru	ur pour po	ru pour op	da pour me

(continued on next page)

Appendix A (*continued*)

Target	Condition				
	12 1234 34	21 1234 43	34 1234 12	43 1234 21	dd 1234 dd
pris	pr pris is	rp pris si	is pris pr	si pris rp	de pris ux
prix	pr prix ix	rp prix xi	ix prix pr	xi prix rp	sa prix le
puis	pu puis is	up puis si	is puis pu	si puis up	fo puis rt
quel	qu quel el	uq quel le	el quel qu	le quel uq	mo quel rt
quoi	qu quoi oi	uq quoi io	oi quoi qu	io quoi uq	pa quoi rt
rien	ri rien en	ir rien ne	en rien ri	ne rien ir	fa rien ux
robe	ro robe be	or robe eb	be robe ro	eb robe or	fa robe im
rose	ro rose se	or rose es	se rose ro	es rose or	hu rose it
sale	sa sale le	as sale el	le sale sa	el sale as	fo sale rt
sang	sa sang ng	as sang gn	ng sang sa	gn sang as	ch sang ef
sauf	sa sauf uf	as sauf fu	uf sauf sa	fu sauf as	ci sauf el
sept	se sept pt	es sept tp	pt sept se	tp sept es	vo sept ir
soir	so soir ir	os soir ri	ir soir so	ri soir os	ce soir nt
tard	ta tard rd	at tard dr	rd tard ta	dr tard at	ch tard ez
tour	to tour ur	ot tour ru	ur tour to	ru tour ot	ge tour ns
tous	to tous us	ot tous su	us tous to	su tous ot	ci tous el
trou	tr trou ou	rt trou uo	ou trou tr	uo trou rt	av trou ec
tuer	tu tuer er	ut tuer re	er tuer tu	re tuer ut	co tuer in
type	ty type pe	yt type ep	pe type ty	ep type yt	mo type is
vent	ve vent nt	ev vent tn	nt vent ve	tn vent ev	cu vent ir
vers	ve vers rs	ev vers sr	rs vers ve	sr vers ev	fa vers ux
vert	ve vert rt	ev vert tr	rt vert ve	tr vert ev	no vert us
vide	vi vide de	iv vide ed	de vide vi	ed vide iv	po vide ur
vite	vi vite te	iv vite et	te vite vi	et vite iv	fa vite ux
voir	vo voir ir	ov voir ri	ir voir vo	ri voir ov	ge voir ns
voix	vo voix ix	ov voix xi	ix voix vo	xi voix ov	pe voix au
vous	vo vous us	ov vous su	us vous vo	su vous ov	ta vous rd
vrai	vr vrai ai	rv vrai ia	ai vrai vr	ia vrai rv	do vrai nc

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