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Short Research Article

Integrating Orthographic Information Across Time and Space

Masked Priming and Flanker Effects With Orthographic Neighbors

Joshua Snell,[1] Daisy Bertrand,[2] Martijn Meeter,[3] and Jonathan Grainger[1]

[1]Laboratoire de Psychologie Cognitive, Aix-Marseille University & CNRS, Marseille, France
[2]Centre d'Etudes et de Recherche en Gestion d'Aix-Marseille, Aix-Marseille University, Aix-en-Provence, France
[3]Vrije Universiteit Amsterdam, LEARN ! Research Institute, Amsterdam, The Netherlands

Abstract: Research has suggested that the word recognition process is influenced by the integration of orthographic information across words. The precise nature of this integration process may vary, however, depending on whether words are in temporal or spatial proximity. Here we present a lexical decision experiment, designed to compare temporal and spatial integration processes more directly. Masked priming was used to reveal effects of temporal integration, while the flanker paradigm was used to reveal effects of spatial integration. Primes/flankers were high-frequency orthographic neighbors of the target (*blue-blur*) or unrelated control words (*head-blur*). We replicated prior observations of inhibition in trials where the neighbor was used as a masked prime, while facilitation was observed in trials where the neighbor was presented as flanker. We conclude that sub-lexical orthographic information is integrated both temporally and spatially, but that spatial information is used to segregate lexical representations activated by spatially distinct sources.

Keywords: reading, orthographic processing, masked priming, flanker paradigm, spatial integration, temporal integration

The processing of orthographic information during reading involves both the temporal and spatial integration of information. Temporal integration of orthographic information concerns the accumulation over time of information extracted from the same spatial location, and is typically evaluated by presenting successive orthographic stimuli (words and nonwords) at the same location (Grainger & Jacobs, 1999). Spatial integration of orthographic information concerns the combination of information extracted from different word locations, at the same point in time (e.g., Dare & Shillcock, 2013). In the present study we investigate the mechanisms that may underlie these integration processes, and in particular, to what extent they may differ.

The masked priming paradigm (Forster & Davis, 1984) has been the paradigm of choice for investigating the temporal integration of information during single word reading. Brief presentation of the prime stimulus is thought to prevent it from being perceived as a distinct perceptual event (Humphreys, Evett, & Quinlan, 1990) hence facilitating integration of information across prime and target (Grainger & Jacobs, 1999). Temporal integration of orthographic information can then be investigated by manipulating the orthographic overlap across prime and target stimuli (e.g., Ferrand & Grainger, 1992; Forster & Davis, 1984; Humphreys et al., 1990).

More recently, spatial integration of orthographic information has been revealed in a paradigm introduced by Dare and Shillcock (2013), the flanking letters lexical decision (FLLD) task, whereby a central target stimulus is flanked by two letters on each side, separated from the target by a space (e.g., "*ro rock ck*"). Here, spatial integration is investigated by means of manipulating the orthographic overlap between the target word and the two flanking stimuli.

In the present study, we focus on one manipulation that has produced contrasting effects in the masked priming and flanker paradigms. The manipulation in question is one where primes/flankers can be orthographic neighbors of target words (e.g., *blue-blur*) or unrelated words

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(e.g., *head-blur*). Prior research has revealed inhibitory effects of orthographic neighbor primes in masked priming (e.g., Davis & Lupker, 2006; De Moor & Brysbaert, 2000; Segui & Grainger, 1990). On the contrary, orthographic neighbor flanking stimuli have been found to facilitate target word processing (Snell, Vitu, & Grainger, 2017).

The inhibitory effects of word neighbor primes found with masked priming have been taken as evidence for competitive processes operating between lexical representations (lexical competition) during visual word recognition (Segui & Grainger, 1990). In support of this interpretation, Jacobs and Grainger (1992) demonstrated that lateral inhibition across co-activated lexical representations in the interactive-activation model (McClelland & Rumelhart, 1981) accurately simulated inhibitory priming effects from orthographic neighbors. It is further known that these effects are affected by word frequency and -lexicality: the strongest inhibition is obtained with a combination of high-frequency prime words and low-frequency target words (Segui & Grainger, 1990), while nonword neighbor primes either generate facilitatory priming or null effects (Forster & Davis, 1991; Forster, Davis, Schoknecht, & Carter, 1987; Van Heuven, Dijkstra, Grainger, & Schriefers, 2001).

The inhibitory effects of neighbor primes but concurrent facilitatory effects of nonword neighbor primes suggest that the *temporal* integration of orthographic information takes place both at the sub-lexical level as well as the lexical level. Following this reasoning, considering that orthographic neighbors facilitated target processing in the flanker paradigm (Snell, Vitu, et al., 2017), Snell et al. concluded that the *spatial* integration of orthographic information operates at the sub-lexical level but not beyond. We further elaborate on this reasoning in the section "Discussion".

The facilitatory parafoveal-on-foveal effect reported by Snell, Vitu, et al. (2017) speaks against a single-channel "one-word-at-a-time" approach to word identification and reading (e.g., Grainger, Dufau, & Ziegler, 2016; Reichle, Pollatsek, & Rayner, 2006). According to Grainger et al. (2016), orthographic information provided by flanking stimuli is integrated into a single channel that outputs a unique word identity. Given a flanker condition "*bl blur ue*," the flanking letters "*bl*" and "*ue*" should combine with orthographic information extracted from the target "*blur*" and provide evidence for the competing word "*blue*," leading to inhibition and not to the facilitation observed by Snell, Vitu, et al. (2017). Instead, their results suggest that despite the spatial integration of sub-lexical orthographic information, the lexical representations that are consequently activated continue to be processed independent from one another – as long as these are associated with spatially distinct sources (see also Snell, Meeter, & Grainger, 2017).

On the other hand, one could argue that this pattern was obtained because orthographic information concerning the competing word was split across the left and right flankers in the Snell et al. experiment, whereas in masked priming the competing word was intact. This caused individual flankers to bear no lexical status (e.g., neither "*ro*" nor "*ck*" in "*ro rock ck*" is a word), as such possibly activating sub-lexical integration processes but not lexical integration processes. It is therefore important to examine effects of word neighbor flankers when these are intact, such as in the example "*blue blur blue*" – while ensuring, crucially, that no facilitation is obtained with the same stimuli and participants in the masked priming paradigm. This was the primary goal of the present study.

Method

Participants

Thirty-two students from Aix-Marseille University gave informed consent to participate in this experiment and received €4. All participants reported to be native to the French language, non-dyslexic, and had normal or corrected-to-normal vision. All participants were naïve to the purpose of the experiment.

Materials

Using the same procedure as in Snell, Vitu, et al. (2017), we retrieved a list of 74 triplets (target word (e.g., "*brut*"), orthographic neighbor (e.g., "*bout*"), and orthographically unrelated control word (e.g., "*noix*") from the French Lexicon Project database (Ferrand et al., 2010). All words consisted of four letters, were nonconjugated, and contained no diacritics. Word pairings were chosen such that orthographic neighbors and control words had a lower lexical decision time (LDT) than their respective target word (for targets, neighbors, and controls, the mean LDT was 671 ms, 618 ms, and 615 ms, respectively).[1] Targets and neighbors only differed in an inner-positioned letter. In a similar fashion we retrieved a list of 74 pseudoword triplets from the French Lexicon Project pseudoword database (Ferrand et al., 2010). These were filler stimuli, not to be included in data analyses. We present the complete stimulus list in the Appendix.

[1] Following Snell, Vitu, et al. (2017) we selected stimuli based on the LDT measure because it more directly reflects the speed with which words become active and reach recognition. Words with a low-LDT value are activated faster, and as such exert stronger inhibition on lexical competitors; hence the choice for low-LDT primes and high-LDT targets.

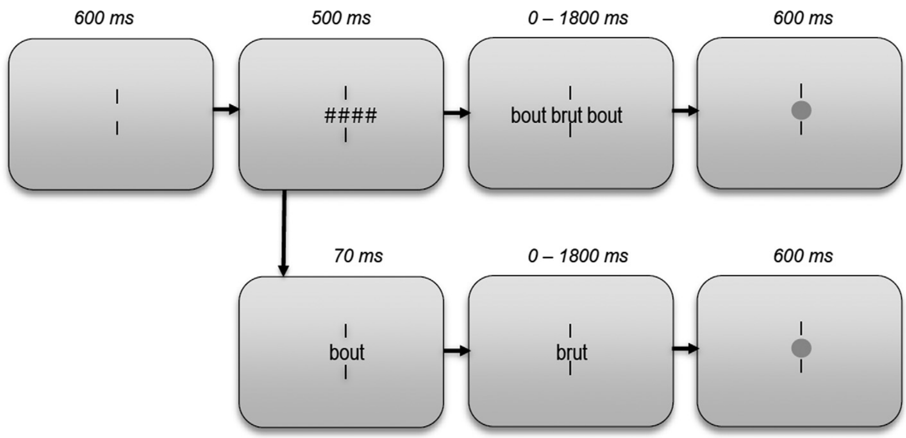

Figure 1. Overview of the trial procedure in the flanker setting (top) and masked priming setting (bottom). The size of stimuli relative to the screen is exaggerated in these examples.

Design

We used a 2 × 2 × 2 factorial design, with word lexicality (*word/pseudoword*), trial type (*masked priming/flanking*), and relatedness of the prime/flanker (*neighbor/control*) as factors. Participants were Latin-squared into two groups, such that every stimulus was presented twice to each participant (once in the neighbor condition and once in the control condition) and in both trial types per two participants. The experiment thus consisted of 296 trials per participant (148 of which were included in the analyses), and these were presented in randomized order.

Apparatus

The experiment was implemented with OpenSesame (Mathôt, Schreij, & Theeuwes, 2012) and presented on a 1,024 × 768 px, 150 Hz computer monitor (Dell, Trinitron series, Dell Inc., Austin, TX, USA). Participants were seated in a comfortable office chair at a distance of 50 cm from the display, so that each character space subtended 0.40 degrees of visual angle. Responses were collected with a keyboard.

Procedure

Before commencing the experiment, participants received instructions both verbally by the experimenter and visually onscreen. Participants were instructed to fixate in between two centrally located vertical fixation bars that were presented throughout the experiment. Figure 1 shows the procedure for each trial type. Both trial types would start with a 500 ms mask consisting of four hashmarks. In masked priming trials, the mask would be replaced by the neighbor/control for 70 ms, followed by the target word. In the flanker trials, the mask would be replaced by the target, with the neighbor/control being presented left and right of the target (separated by a single character space). Following Snell, Vitu, et al. (2017), all words were presented in 18-point monospaced font (droid sans mono; the default monospaced font in OpenSesame) and in lowercase. The target would stay onscreen until participants pressed a left- or right-handed key for *pseudoword* or *word*, respectively. Participants were instructed to respond as quick and accurate as possible, and the maximum allowed response time (RT) was 1,800 ms after the target onset. Participants received feedback in the form of a briefly presented centrally located green or red dot, for correct and incorrect responses, respectively. The next trial began immediately after the 600 ms feedback signal.

Results

Only correctly answered trials (93.14%) were included in the analysis of response times (RT).[2] For our analyses of RTs and error rates we used linear mixed-effect models (LMMs) with items and participants as crossed random effects (Baayen, 2008). To meet the models' assumption that the data were normally distributed, RTs were inverse-transformed (−1,000/RT) prior to the analyses. The models were fitted with the lmer function from the lme4 package (Bates, Maechler, Bolker, & Walker, 2015) in the R statistical computing environment. Following Barr, Levy, Scheepers, and Tily (2013) we determined the maximal random effect structure permitted by the data. This led us to include by-item and by-participant random intercepts, as well as by-item and by-participant random slopes

[2] The raw data files can be accessed online at https://osf.io/tq38d/.

$$RT \sim \textbf{Relatedness} + (\textbf{1+Relatedness|Participant}) + (\textbf{1+Relatedness|Item})$$

Figure 2. The typical LMM structure used to analyze the present data. Here, RT is the dependent variable, whereas the model terms are presented to the right of the tilde ("~") character. The first term (Relatedness) is a fixed effect. The next two terms are random effects, with the random factors (respectively, Participant and Item) being presented right of the bar ("|") character. The expression to the left of the bar indicates the inclusion of random intercept ("1") and random slope ("Relatedness").

(Figure 2). We report regression coefficients (*b*), standard errors (*SE*) and *t*-values. Fixed effects were deemed reliable if $|t| > 1.96$ (Baayen, 2008). Logistic LMMs (fitted with the glmer function) were used to analyze the error rates. Below we present separate analyses for flanker trials and masked priming trials, followed by a direct comparison of the two trial types.

Table 1. Response times (ms) and error rates (probability)

	Response times		Error rates	
Condition	Neighbor	Control	Neighbor	Control
Flanker trials	731 (171)	742 (164)	.072 (.045)	.059 (.050)
Masked priming	707 (161)	697 (149)	.058 (.044)	.039 (.048)

Note. Values in between parentheses indicate standard deviations.

Flanker Trials

We replicated the finding of Snell, Vitu, et al. (2017) that target processing is facilitated by orthographic neighbor flankers, as RTs were significantly shorter in the neighbor condition as compared to the control condition ($b = 0.03$, $SE = 0.01$, $t = 2.54$; condition means in Table 1). The error rate did not differ significantly between conditions ($b = 0.25$, $SE = 0.19$, $z = 1.36$).

Masked Priming Trials

Whereas our neighbor stimuli were found to facilitate target processing in the flanker condition, the opposite pattern was found in the masked priming trials. An inhibitory effect was found in the error rates, with significantly more errors following neighbor primes than control primes ($b = 0.43$, $SE = 0.22$, $z = 1.98$). The pattern of RTs followed the same direction numerically (see Table 1), but did not reach significance ($b = -0.02$, $SE = 0.01$, $t = -1.27$).[3]

Comparison of Trial Types

To compare the two trial types directly,[4] we entered the interaction of Relatedness × Trial type in a separate model. The effect in RTs of prime/flanker on target processing turned out to interact significantly with trial type ($b = 0.05$, $SE = 0.02$, $t = 3.15$), thus confirming the significance of the opposite pattern of effects found in the two trial types (Table 1). No significant interaction was established in the error rates ($b = 0.19$, $SE = 0.28$, $z = 0.69$; Table 1).

Lastly, there was a noteworthy main effect of trial type on RTs, with increased RTs in the flanker setting compared to the masked priming setting ($b = 0.06$, $SE = 0.01$, $t = 5.67$). This suggests that flankers generally perturbed target processing more than primes.

Discussion

A lexical decision experiment examined the effects of orthographic neighbors on target word recognition when the neighbors were either presented as masked primes immediately before the target word at the same location, or presented as flanking words simultaneously with, and to the left and to the right of the target word. The general aim was to compare the temporal integration of orthographic information as revealed by masked priming, with the spatial integration of orthographic information as revealed by the flanker task. Insight into the respective natures of these different types of integration further provides a means to test two opposing accounts of word identification and reading: a single-channel, one-word-at-a-time account (e.g., Grainger et al., 2016; Reichle et al., 2006) and a multichannel, parallel word identification account (e.g., Snell, Meeter, et al., 2017).

According to the single-channel model proposed by Grainger et al. (2016), orthographic processing operates in parallel across multiple words during sentence reading (cf., Engbert, Nuthmann, Richter, & Kliegl, 2005; Reilly & Radach, 2006), and the orthographic information extracted from different words is integrated into a single processing

[3] It should be noted that inhibitory prime effects are not always established in RT data. Zimmerman and Gomez (2012) have argued that the amount of attentional resources spent on processing of the prime directly affects the chance of finding an inhibitory effect, and that longer prime durations might as such lead to stronger inhibitory effects.

[4] We acknowledge that such a comparison is complicated by the many differences between the two paradigms (we further elaborate on these differences in the section "Discussion"), but believe that a direct comparison is nonetheless relevant in the context of the present study.

channel that outputs a unique word identity. We reasoned that if this were the case, then the presence of an orthographic neighbor as flanking stimulus should lead to inhibition of target word processing, mimicking the effects seen when orthographic neighbors are presented as masked prime stimuli (Davis & Lupker, 2006; De Moor & Brysbaert, 2000; Segui & Grainger, 1990). Snell, Vitu, et al. (2017) put this reasoning to test and, on the contrary, found that parafoveal orthographic neighbors facilitated target word processing both in a sentence reading setting as well as in the flanker task (e.g., "*bl blur ue*"). When used as flanker, however, the orthographic neighbor was divided either side of the target, contrary to the use of complete prime stimuli in masked priming experiments. The results of the present experiment show that presenting whole-word flankers on either side of the target (e.g., "*blue blur blue*") produces a similar facilitatory effect, the size of the effect being 11 ms compared with the 14 ms effect in the Snell, Vitu, et al. (2017) study.[5] Crucially, in the present study, the same participants showed an inhibitory priming effect with the same stimuli when these were presented as primes and targets in a masked priming procedure.

Why then do orthographic neighbor flanking stimuli facilitate target word identification in the flanker task? The answer offered by Snell, Vitu, et al. (2017) is that orthographic information extracted from distinct spatial locations is integrated sub-lexically (see also Angele, Tran, & Rayner, 2013; Grainger, Mathôt, & Vitu, 2014; Snell, Vitu, et al., 2017), hence facilitating target word recognition when there is orthographic overlap. What is novel in Snell, Meeter, et al.'s (2017) account is that spatial information is used to keep track of which activated word representation belongs to which spatial location, hence enabling parallel higher-level processing of multiple stimuli. The fact that this parallel processing is geared to output several distinct word identities means that flanker and target stimuli do not interfere at the level of lexical processing and beyond. Thus, whereas sub-lexical orthographic information is integrated across spatially *and* temporally distinct stimuli, lexical integration takes place within- rather than across spatial locations.

On a methodological note, it is important to consider the various differences between the masked priming and flanker trials – in particular with respect to the availability of the prime/flanker stimulus during target processing – and whether or not such differences may have contributed to the opposing (facilitatory vs. inhibitory) effects obtained in each respective setting. Concretely, one might argue that the neighbor could have been processed to a further extent in flanker trials than in masked priming trials, given that the neighbor was only available for 70 ms in the latter trial type whereas it was available during the whole stimulus-response interval in the former trial type. On the other hand, one might argue that the constraints imposed by visual acuity cause foveal processing of the prime stimulus to be of higher quality than parafoveal processing of the flanker stimulus, as such compensating for their different presentation time. Importantly, we opted to keep flanking stimuli onscreen rather than to have them disappear after 70 ms because the offset of these stimuli would have directed attention away from the fovea (similar to a stimulus onset). Crucially, even if flankers were processed to a further degree than primes, this should have then only increased the effects that were established here. Indeed, it is clear that the potentially increased processing of flankers compared to primes did not lead to inhibition, as might otherwise be expected following deeper integration of information between orthographic neighbors.

In sum, the present results underline the idea that the integration of orthographic information from multiple words can impact the recognition process in various ways. The outcome of this integration process seems to depend strongly on the words' spatial locations, in line with the idea that readers keep track of which word belongs to which position: when word representations are tied to the same spatial location, the integration of information is carried on to the lexical level, where lexical competition perturbs the recognition process. In contrast, when word representations are tied to different spatial locations, this segregation allows for parallel independent lexical processing, resulting in stronger activation and faster word recognition.

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Joshua Snell
Laboratoire de Psychologie Cognitive
Aix-Marseille University
3 place Victor Hugo
13331 Marseille
France
joshua.snell@hotmail.com

Appendix

Table A1. Stimuli used in the present experiment

Words			Pseudowords		
Target	Neighbor	Control	Target	Neighbor	Control
Aile	Aide	Fond	Orve	Ouve	Atal
Aire	Aile	Moto	Rine	Rone	Abac
Base	Baie	Rond	Afit	Adit	Spen
Bise	Bile	Poux	Stin	Suin	Moce
Bond	Bord	Arme	Bral	Bril	Uste
Boxe	Boue	Rail	Puif	Poif	Lage
Brin	Brun	Taxe	Nile	Nole	Carc
Brut	Bout	Noix	Psat	Psut	Ulle
Cage	Cave	Soif	Guve	Guge	Insi
Case	Cape	Midi	Assa	Asta	Itre
Chic	Choc	Peau	Tuce	Tute	Glin
Chut	Chat	Lire	Uise	Uide	Alon
Clou	Chou	Haie	Vret	Vuet	Gnal
Cote	Code	Pays	Oche	Ocle	Fida
Crue	Crie	Clan	Olde	Olle	Ahui
Cuve	Cube	Poil	Sabe	Sube	Rêt
Dame	Date	Noir	Vave	Vate	Murf
Dune	Dupe	Sort	Vure	Vuie	Imci
Fade	Face	Joli	Lube	Luve	Giot
Fine	Fixe	Drap	Nouf	Noif	Pala
Flic	Fric	Menu	Onue	Oque	Gami
Flot	Foot	Abri	Jine	Jive	Momb
Flux	Feux	Amie	Cude	Cuse	Gnai
Gage	Gaie	Unir	Tese	Tose	Haid
Gaie	Gare	Bouc	June	Juse	Tipt
Gras	Gros	Dent	Vore	Vose	Jaut
Huer	Hier	Golf	Itie	Ilie	Ranu
Joue	Joie	Rang	Erle	Erme	Vonc
Juge	Jupe	Gris	Coui	Cofi	Alve
Laid	Lard	Peur	Adre	Adie	Ofci
Lave	Lame	Cuir	Uite	Uire	Phol
Lion	Lien	Bref	Vare	Vace	Noui
Logo	Loto	Nier	Cona	Cena	Didi
Luge	Loge	Pain	Oute	Oste	Misi
Lune	Luxe	Fort	Soge	Sige	Trit
Mime	Mine	Sauf	Spel	Suel	Wadu
Mont	Mort	Vive	Arne	Arie	Mout
Moue	Mode	Pair	Onsa	Ofsa	Dute
Muse	Mule	Nord	Chen	Cien	Gord
Nerf	Neuf	Plat	Geuf	Gerf	Acci
Noce	Note	Juin	Iage	Inge	Stou
Ocre	Ogre	Aigu	Amit	Anit	Greu
Onde	Onze	Mari	Jote	Jore	Clai
Page	Pape	Film	Sute	Supe	Dida
Paix	Prix	Bleu	Fien	Fren	Solu

(Continued on next page)

Table A1. (Continued)

Words			Pseudowords		
Target	Neighbor	Control	Target	Neighbor	Control
Paon	Pion	Fier	Stre	Stue	Ilci
Pieu	Pneu	Tour	Arni	Arti	Ouge
Pipe	Pile	Trou	Dave	Dade	Gonc
Pire	Pure	Thon	Arve	Aive	Ucun
Pont	Port	Mare	Euve	Eule	Drif
Porc	Parc	Test	Buge	Bune	Tion
Port	Part	Beau	Poge	Poce	Arut
Pote	Pose	Char	Nobe	Noge	Phif
Pure	Puce	Loin	Ique	Idue	Atat
Race	Rage	Mois	Gict	Gint	Nala
Raie	Rate	Doux	Ajet	Anet	Frum
Rame	Rare	Bloc	Jave	Jace	Rodi
Ride	Rire	Long	Nora	Noma	Eige
Rime	Rive	Solo	Nent	Nept	Jurf
Robe	Rose	Saut	Oile	Oble	Daud
Roue	Robe	Bain	Ince	Inse	Psou
Rude	Ride	Kilo	Mune	Muve	Bara
Ruse	Rude	Foin	Vact	Valt	Orio
Sain	Sein	Clef	Bome	Boce	Drai
Sale	Sage	Coin	Ogne	Ogme	Fauf
Scie	Soie	Jury	Cavu	Catu	Phre
Sein	Soin	Papa	Nire	Nure	Spho
Soja	Soda	Lent	Alse	Alme	Cigi
Taux	Toux	Bois	Enre	Ente	Vima
Toit	Tort	Grec	Suve	Sule	Apit
Trac	Troc	Sens	Zote	Zode	Afil
Troc	Truc	Lieu	Oire	Oige	Satu
Vent	Vert	Bras	Imin	Itin	Stet
Vice	Vite	Tard	Igle	Igue	Uant
Vide	Vice	Abus	Fuve	Fube	Clat