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Neighborhood-frequency effects when primes and targets are of different lengths

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Abstract The present study provides a further investigation of the neighborhood-frequency effect. Using the masked priming procedure, we found that the neighborhood-frequency effect is obtained not only with primes and targets of the same length but also with primes and targets of a different length. This result is not compatible with most current versions of the interactive activation model. Implications of the finding are discussed.

Introduction

Recent years have seen an enormous increase in our understanding of visual word recognition, partly due to a fruitful interaction between simulation models and new tasks designed to test predictions of the models. One of these paradigms that has been very useful is the masked priming procedure in which participants have to respond to target words that are preceded by a consciously unnoticeable masked prime. Due to the unawareness of the prime, effects observed with this procedure can be attributed to automatic processes at the early stages of word processing. Using this paradigm, Segui and Grainger (1990) found that prior presentation of a masked neighbor prime (an orthographically related word that differs from the target word in only one letter position) resulted in a longer reaction time to the target word. The inhibitory effect only occurred when the neighbor prime was of higher frequency than the target word. This effect, which Segui and Grainger termed the neighborhood-frequency effect, has since been replicated in a number of different paradigms, including lexical decision (e.g., Grainger & Segui, 1990), eye-gaze duration (Grainger, O'Regan, Jacobs & Segui, 1989) and speeded identification (Grainger & Jacobs, 1996).

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The neighborhood-frequency effect was expected on the basis of the interactive activation model (McClelland & Rumelhart, 1981), which assumes mutually inhibitory connections between lexical representations. Due to the orthographic overlap between a word and its neighbor, the neighbor is activated by the presentation of the target word, and the activation must be inhibited before the target word can be identified. This results in longer reaction times. The frequency effect is explained by assuming that the activation level of a lexical representation depends on the printed frequency of the word.

Previous research on the neighborhood-frequency effect has been limited to neighbors of the same length as the target word. This restriction is partly due to Coltheart, Davelaar, Jonasson, & Besner's (1977) definition of a word neighbor and partly to the fact that most simulation models of visual word recognition were confined to a single word length. However, there are some indications that during prime presentation, lexical representations of different lengths than the target word can become activated and may affect target word recognition. For example, Grainger & Segui (1990) found that in a progressive demasking task, the majority of errors made by the participants concerned the substitution, addition, or deletion of a single letter. These findings suggest that during the process of visual word recognition, not only lexical units of the same length as the target word are activated, but also units of a different length.

The aim of the present study was to investigate whether the neighborhood-frequency effect can be extended to primes and targets of a different length. For this purpose, the masked priming procedure in combination with a lexical decision task was used.

Method

Participants. Forty-eight undergraduate psychology students of the University of Ghent participated in the experiment in exchange for course credits. All were native speakers of Dutch and had normal or corrected-to-normal vision.

Materials. All word stimuli were selected from the CELEX database (Baayen, Piepenbrock, & Van Rijn, 1993). A total of 96 targets (48 words and 48 non-words) were presented. All target words were four- or five-letter Dutch words. Half of the targets were preceded by a prime of the same length (see App. 1), the other half by a prime of a different length (see App. 2). Target words were low-frequency words (mean logarithmic frequency per million = 0.5). Prime words were high-frequency neighbor words (mean logarithmic frequency per million = 2.1). Target words were selected so that they had at least one higher-frequency neighbor of the same length. For each target word an unrelated control prime (of the same frequency as the neighbor prime, but with no letters in common with the target word) was selected. For half of the participants, the odd target words of the list were presented with their neighbor prime and the even words with an unrelated control. For the other half of the participants, the combination was reversed.

In addition, 48 non-words were constructed. Half of these non-words were preceded by a neighbor prime (i.e., a word that could be formed by changing one letter of the non-word), the other half by an unrelated control word. Half of the primes were of the same length as the non-word, the other half were of a different length (plus or minus one letter). Care was taken to ensure that all non-words were pronounceable and orthographically legal strings.

Procedure. Stimuli were presented in isolation at the center of a display screen connected to an IBM-compatible personal computer. The masked prime procedure in combination with a lexical decision task was used. On each trial, two vertical lines appeared at the center of the screen. Between these two lines a forward mask in the form of five hash signs (#####) appeared for a duration of 500 ms. These were first replaced by the prime word for 57 ms and then by the target stimulus. Both stimuli were centered relative to the fixation location (i.e., participants looked at the third letter of the five-letter words and between the second and the third letter of the four-letter words). The target remained on the screen until the participant indicated "word" or "non-word" by pressing one of two keys of a response box. The next trial started one second later. The prime word was presented in lower-case letters, the target word in upper-case letters to minimize physical similarity effects. Participants were instructed to respond as fast and as accurately as possible. Stimulus presentation was randomized with a different order for each participant. The responding hand for the word and the non-word trials was counterbalanced across participants.

Results

Mean reaction times and error rates as a function of prime-target relatedness are shown in Table 1 (see also the appendices for the RTs and PEs of the individual words). Incorrect responses (9% of the data for the words, 5% of the data for the non-words) and RTs shorter than 300 ms or longer than 2000 ms (1% for both the words and the non-words) were omitted from the latency analyses. Mean reaction times and error data were analyzed with ANOVAs including two variables: the Length similarity of prime and target, and the Orthographic relatedness of the prime. Results are reported both by participants ($F1$) and by items ($F2$).

For the reaction times of the word trials, there were significant main effects of Length similarity, $F1(1,47) = 39.9$, $p < .01$; $F2(1,46) = 7.1$, $p < .05$, and Orthographic relatedness, $F1(1,47) = 10.1$, $p < .01$; $F2(1,46) = 5.8$, $p < .05$, and no interaction effect ($F1$, $F2 < 1$). Reaction times were longer for target words that were preceded by a prime of a different length and for target words that were preceded by an orthographically related neighbor. Planned comparisons showed that the 14-ms inhibitory effect of orthographic relatedness in the same-length condition was not significant, $F1(1,47) = 1.91$, $p > .15$; $F2(1,46) = 1.54$, $p > .20$, but that the 21-ms inhibitory effect in the different-length condition was significant $F1(1,47) = 4.3$, $p < .05$; $F2(1,46) = 4.6$, $p < .05$. The analysis of the percentage of errors only returned a significant effect of Length similarity, $F1(1,47) = 21.9$, $p < .01$; $F2(1,46) = 8.0$, $p < .01$, and no reliable effect of Orthographic relatedness, $F1(1,47) = 1.3$; $F2(1,46) = 1.2$, nor an interaction ($F1$, $F2 < 1$).

Table 1 Mean reaction times (in milliseconds) and error rates (in percentage) for words and non-words as a function of the prime and whether prime and target were of the same length (SL) or of a different length (DL)

	Words				Non-words			
	RT		PE		RT		PE	
	SL	DL	SL	DL	SL	DL	SL	DL
Neighbor prime	664	708	6.7	13.0	738	754	3.9	5.0
Control prime	650	687	5.5	11.8	737	770	4.6	7.6
Difference	14	21	1.2	1.2	1	−16	−0.7	−2.5

Because the materials in the different-length condition consisted of 12 primes that were longer than the target (e.g., *laars–AARS*) and 12 primes that were shorter (e.g., *kast–KWAST*), we were able to examine whether shorter and longer primes produced different effects. This was not the case, as only the $F1$ analysis of the error rates turned out to be reliable, RT: $F1(1,46) = 1.93$, $p > .17$; $F2(1,11) = 2.35$, $p > .15$; PE: $F1(1,47) = 12.04$, $p < .01$; $F2(1,11) = 3.10$, $p > .10$. Other exploratory analyses we ran (e.g., differences between letters changed at the beginning and letters changed at the end, differences between consonants that were changed and vowels that were changed) did not yield significant combinations of $F1$ and $F2$ statistics, either. Therefore, they will not be presented at full length here. (See the appendices for the individual word data.)

For the non-word trials, there was only a significant effect of Length similarity of prime and target, both for the reaction times, $F1(1,47) = 17.6$, $p < .01$; $F2(1,46) = 4.5$, $p < .05$, and the percentage of errors, $F1(1,47) = 5.3$, $p < .05$; $F2(1,46) = 2.1$, $p > .10$. More errors were made when the primes and the target non-words were of different lengths. No other effect approached significance (all Fs < 1.2).

Discussion

The results of this experiment replicate previous observations of neighborhood-frequency effects: Lexical decision latencies are longer for words preceded by an orthographic neighbor than for words preceded by an unrelated control prime. More importantly, however, our results show that the effect is present not only for prime-target pairs of the same length but also for pairs of a different (neighboring) length. This suggests that during the process of word recognition, not only the lexical entries of words of the same length, but also lexical entries of words of a different length are activated.

It may be remarked that, despite the main effect of orthographic relatedness and the absence of an interaction between orthographic relatedness and length similarity between prime and target, planned comparisons showed that the 14-ms inhibition effect in the same-length condition was not reliable, and hence that we failed to replicate Segui and Grainger (1990). It is not clear what caused this reduced figure, but it may be interesting to note that Brysbaert, Lange, and Van Wijnendaele (in press, Exp. 3) used exactly the same materials (albeit in a different context) and obtained a reliable 25-ms inhibition effect in the same-length condition. Therefore, we are confident that the neighbor inhibition effect is reliable in Dutch and comparable for stimulus pairs in which prime and target are of the same length and stimulus pairs in which prime and target are of different lengths.

Further evidence for the fact that visual word recognition does not depend only on neighbors of the same length has recently been obtained by Van Heuven and Dijkstra.[1] In two experiments, participants performed a lexical decision task on four-letter Dutch target words. Target words differed with respect to the number of five-letter neighbors, while the number of four-letter neighbors was matched across items. Words with five-letter neighbors were found to lead to slower RTs than words without five-letter neighbors, and the size of the inhibition effect depended on the frequency of the five-letter neighbors. Using somewhat different stimuli, Drews and Zwitserlood (1995) also obtained evidence for an inhibitory effect of neighbors of a different length. In a series of experiments using Dutch and German stimulus materials, Drews and Zwitserlood presented primes (e.g., *kerst*) followed by a shorter target (e.g., *KERS*), matched for frequency. An inhibitory effect of orthographic similarity was present in all lexical decision experiments, and this was true both with masked and unmasked prime presentation. Thus, as in the present study, primes of a different length than the target did produce interference.

These findings suggest that orthographic neighbors are not defined exclusively at the level of individual letter positions, but also in terms of other sublexical levels of word recognition. For instance, these sublexical levels might be the wickelgraphs used by Seidenberg and McClelland (1989) or the distinction between word onset, word nucleus, and word coda proposed by several authors (e.g., Taft, 1992). In addition, our findings have implications for studies that look at the effects of neighborhood density (i.e., the number of neighbors of a target word) on word processing, as it may very well be that the densities used thus far have not been appropriately defined because they were restricted to words of the same length.

[1] Personal communication: January 16, 1998.

One issue that remains is why participants reacted slower and made twice as many errors when prime and target were of a different length, despite the fact that the word frequencies in both conditions were matched. A possible explanation could be found in the "mask appropriateness" effect on word recognition. Jordan (1990) reported that in a backward-masking paradigm, performance was better if the masks were of the same size as the words, compared to conditions where the masks were longer or discontinuous. According to Smith, Jordan, and Sharma (1991), participants extracted information about word length or word boundaries from the mask and used this information for target word processing. Thus, although the neighborhood of a word is not confined to the words of the same length, information about the length of a word does not seem to be totally neglected in visual word recognition.

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Appendix 1

Items used in the experiment, with primes and targets of the same length. *Log fr* = the logarithm of the frequency on a total of 42,380,000 counts in order to avoid negative numbers; *RT* = reaction time correct responses, *PE* = percentage of errors

Target word	log fr	Neighbor prime	log fr	RT	PE	Control prime	log fr	RT	PE
BUIL (bump)	1.9	buik (belly)	3.5	688	.08	maan (moon)	3.4	742	.00
DEUK (dent)	2.2	druk (busy)	3.8	670	.13	zorg (care)	3.7	640	.04
EIKEL (acorn)	2.3	enkel (only)	4.4	590	.00	soort (sort)	4.2	617	.00
HERT (deer)	2.5	hart (heart)	3.9	658	.00	wijn (wine)	4.0	604	.00
KLONT (lump)	1.8	klant (customer)	3.3	866	.25	dwaas (fool)	3.1	765	.21
KOEK (cake)	2.6	boek (book)	4.2	638	.04	naam (name)	4.3	613	.00
KOORD (cord)	2.5	woord (word)	4.4	679	.21	licht (light)	4.3	609	.08
KRENT (currant)	1.6	kreet (cry)	3.2	675	.08	slijm (mucus)	2.3	705	.04
LANS (lance)	2.4	kans (chance)	3.9	637	.17	idee (idea)	4.0	752	.13
LEDER (leather)	1.7	leger (army)	3.5	653	.08	smaak (taste)	3.5	621	.04
LUIS (louse)	2.3	huis (house)	4.4	666	.00	keer (time)	4.3	636	.04
MEEL (flour)	2.4	deel (part)	4.2	633	.13	paar (pair)	4.3	687	.21
MEREL (blackbird)	2.3	kerel (guy)	3.4	589	.04	haast (hurry)	3.6	607	.00
MEST (manure)	2.3	rest (rest)	3.7	633	.00	loop (run)	3.6	595	.17
MIER (ant)	2.5	meer (more)	4.8	601	.08	hand (hand)	4.6	595	.00
RASP (grater)	1.3	ramp (disaster)	3.0	760	.08	loon (pay)	3.1	693	.04
RIEK (fork)	1.7	riet (reed)	2.8	782	.17	lust (desire)	3.0	789	.13
SCHEP (scoop)	2.0	schip (ship)	3.7	781	.04	kaart (card)	3.6	731	.08
TANG (tongs)	2.4	gang (passage)	3.9	687	.00	dier (animal)	3.9	603	.00
VETER (lace)	2.3	meter (meter)	3.7	668	.04	maand (month)	4.0	601	.00
VLAAI (flan)	1.2	vlaag (gust)	2.5	633	.00	boete (fine)	2.6	677	.13
ZAAG (saw)	2.1	laag (low)	4.0	586	.00	been (leg)	3.9	602	.00
ZEGEL (stamp)	2.3	regel (rule)	3.8	572	.50	spoor (track)	3.5	577	.00
ZOOL (sole)	2.3	zoon (son)	3.9	659	.00	heer (man)	4.0	609	.00
	–		–				–		
	2.1		3.7				3.7		

Appendix 2

Items used in the experiment, with primes and targets of a different length

Target word	log fr	Neighbor prime	log fr	RT	PE	Control prime	log fr	RT	PE
AARS (arse)	1.8	laars (boot)	3.0	763	.04	engel (angel)	3.0	690	.08
ADER (vein)	2.7	ander (another)	4.2	657	.04	thuis (home)	4.0	628	.00
BOOR (brace)	1.9	boord (border)	3.3	694	.08	keuze (choice)	3.5	651	.13
BRONS (bronze)	2.0	bron (well)	3.4	646	.00	daad (act)	3.4	680	.04
EVER (wild boar)	2.0	oever (bank)	3.1	847	.33	wacht (watchman)	3.1	770	.42
FOLIE (foil)	2.0	olie (oil)	3.3	754	.08	wand (wall)	3.3	726	.08
GEEUW (yawn)	1.7	eeuw (century)	4.0	671	.13	bank (bench)	3.7	688	.17
GOOT (wastepipe)	2.4	groot (big)	4.7	728	.04	leven (life)	4.7	718	.04
GROEF (groove)	2.1	grof (coarse)	3.1	745	.17	paus (pope)	3.1	728	.17
KEUR (hallmark)	2.0	kleur (color)	3.8	715	.21	sinds (since)	3.8	708	.08
KLEI (clay)	2.5	klein (small)	4.3	653	.08	vraag (question)	4.3	636	.04
KRAAL (bead)	2.3	kaal (bald)	3.2	736	.13	thee (tea)	3.3	704	.17
KRAAM (stall)	2.3	raam (window)	3.9	739	.13	tien (ten)	3.9	702	.08
KWAST (brush)	2.3	kast (cupboard)	3.3.	669	.04	vuil (rubbish)	3.3	669	.04
LENIG (limber)	2.4	enig (only)	4.4	609	.00	stuk (piece)	4.1	674	.00
LINK (link)	2.0	links (left)	3.6	706	.25	jeugd (youth)	3.4	821	.04
LIST (trick)	2.4	lijst (list)	3.7	756	.17	paard (horse)	3.8	587	.13
MEES (tit)	2.5	meest (most)	4.2	745	.17	zoals (as)	4.6	749	.21
NEVEN (next to)	1.0	even (even)	4.5	708	.04	laat (late)	4.5	647	.13
ROOM (cream)	2.4	droom (dream)	3.7	657	.38	helft (half)	3.5	645	.17
ROVER (robber)	2.4	over (over)	5.1	795	.13	zich (himself)	5.2	733	.08
RUIS (noise)	1.9	kruis (cross)	3.2	817	.25	plaat (plate)	3.2	692	.17
SLIJK (mud)	2.2	lijk (corpse)	3.2	669	.04	vaag (vague)	3.5	644	.00
STAAK (stake)	2.0	taak (task)	3.8	656	.17	eind (end)	3.8	669	.25
	–		–				–		
	2.1		3.7				3.7		