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Levels of Competition in Lexical Access

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Abstract

For a visual word to be recognised it must be singled out from among all other possible candidates. The less distinct a lexical entry is the more candidates there will be competing with it, and so recognition will be inhibited. In opposition to this view the findings of Andrews (1989,1992) show a facilitatory effect of neighborhood size; low frequency words which bore orthographic similarity to many other words were recognised more quickly, than those with fewer neighbors. Since neighborhood size as determined by Colthearts "N" metric was designed as essentially a measure of lexical similarity, Andrews result could be interpreted as evidence for lexical level facilitation. In the present experiments we repeat both the ldt and naming studies of Andrews using a more tightly controlled stimulus set. Only in LDT are her results supported, in naming we find no facilitatory effect of neighborhood size. We discuss why any truly lexical level facilitation is inherently improbable.

Introduction

One of the most fundamental issues of lexical access concerns how the correct lexical entry is selected from among possible alternatives. In modeling this selection the natural analogy is one of competition, a process in which just one word wins and is recognised. Competition at a variety of descriptive linguistic levels is considered in attempts at modeling the characteristics of both auditory and visual word recognition. In the present paper we consider only the visual modality.

At a word level of description, a competitive edge appears to be given to those words occurring more frequently, hence they are recognised with greater speed than less frequent words (Andrews 1989; Andrews 1992; Grainger and Segui 1990; Marslen-Wilson 1990).

At a sub-lexical level sharing letters or features with other words may render a word less distinctive, as it is very similar to a large number of other lexical entries, and so less separable from them. It will therefore take longer to recognise a word that is perceived to be similar to many other words, than a word which receives less interference from like forms, (Luce, Pisoni and Goldinger 1990).

Just as commonly occurring words are easier to recognise than rarer ones, so frequent sub-lexical units such as letters, bigrams, or phonemes will give rise to faster recognition as a result of increased exposure. If part of the perceptual process is however the recognition of these orthographic or phonemic components, of which visual and auditory word stimuli are composed, then a word which shares common components with lots of other words will have an increased ease of recognition. Instead of acting as competitors alike forms may act as co-conspirators which facilitate a words chance of being correctly identified (Andrews 1989; Andrews 1992; Grainger 1990).

Coltheart et al. (1977) put forward the N metric as a measure of orthographic similarity. N corresponds to the number of new words generated by replacing any letter of a target word with another letter in the same position (e.g. HILL; fill, hell, hilt). Hence N represents the number of orthographic neighbors a word has; the number of words to which it bears visual similarity.

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In models of lexical access which assume a serial metaphor, like that of Forster (1989), it would be possible for neighbors to have no effect at all indicating that they are not sufficiently similar to the access code for the target to trigger a match. If neighborhood size did produce an effect, words with large neighborhoods would be expected to result in longer response latencies than those in small neighborhoods. A large neighborhood would give more candidates to be checked against the target and so more interruptions to the search process.

In a serial search model high and low frequency words would however have different predicted neighborhood effects. It is the case that within neighborhoods there are more lower frequency words than high frequency words. High frequency words are always checked before lower frequency words so neighborhood size should have little effect on high frequency words: there will be few, if any, higher frequency words in the neighborhood to be checked before a very frequent target. For a low frequency word the neighborhood will contain many higher frequency words to be checked before the target. A serial search model therefore predicts an inhibitory effect of neighborhood size for low frequency words.

Within McClelland and Rummelharts (1981) specification of an interaction activation framework, words containing letters common to many words will cause activation of these words, thus feeding activation back into the letter level. McClelland and Rumelhart (1981) refer to this as the "gang effect". In addition to activation attributable to the stimulus, a word is activated by the letter level activation feeding back from its neighbors. Although neighbors will also activate non-target letters this is offset by the presence of bottom-up inhibition acting upon the non-present letters. The model therefore predicts a facilitatory effect of large neighborhoods, as more neighbors means more activation.

The process of Lateral inhibition within an IAM means the model is also able to accommodate the finding that large neighborhoods may inhibit a words recognition. Via lateral inhibition any active word node will send out inhibition to all other active nodes. A model of interactive activation therefore permits both facilitatory and inhibitory effects of neighborhood size. Which of these it favors depends on the parameter settings determining between level excitation and word level inhibition. The model makes no prediction as to what determines these parameters or the relation between them.

Andrews (1989,1992) examined neighborhood effects using a factorial manipulation of neighborhood size and word frequency. With both lexical decision and naming tasks, Andrews found an interaction of word frequency and neighborhood size: facilitatory effects of neighborhood size were observed for low, but not for high frequency words. As Colthearts N metric is a measure of lexical similarity the Andrews result appears to imply lexical level facilitation between words. This result demands further investigation because it stands in contradiction to those which report inhibition from like forms in visual word recognition, and presents a challenge to models of lexical access.

Experiment 1: lexical decision

Method

Subjects: The subjects were twenty four undergraduate and post graduate student volunteers.

Materials and design: The word stimuli were forty, four letter words, none of which were homophones. They were selected to conform to 2 × 2 factorial design where the two factors were word frequency (high/low) and neighborhood size (large/small). High frequency words had a mean of 123 occurrences per million, and low frequency words had a mean of 3 occurrences per million according to the norms of Kucera and Francis (1967). Mean neighborhood size, as determined by Colthearts "N" metric, was 20.25 for large neighborhoods and 7.9 for small neighborhoods. Ten stimuli were selected to fill each cell of the design so that word frequency was matched across neighborhood and neighborhood size was matched across each frequency level. Word onset and bigram frequency was also equated across the four cells. The letter bigrams used to determine a word bigram score were taken from a million word sample of the USENET news group.

Subjects were randomly assigned to one of two non-word conditions either wordlike or unwordlike. Both nonword conditions had total bigram frequencies equivalent to the word conditions. The wordlike nonwords were in two sets, those with large neighborhoods (19.5) and those with small neighborhoods (7.35). Unwordlike nonwords are those having illegal or very rare letter clusters. Once a four letter sequence has such a rare cluster within it, the number of neighbors that can be made by altering one letter of that word becomes quite small, especially when there is the added constraint of equating the bigram frequency with other stimulus conditions. For the unwordlike nonwords the division of large and small neighborhoods was therefore not possible.

Procedure: Subjects were tested individually in a sound-proof room. They were told that they would

		Frequency		
	N'hood	High	Low	Mean
Wordlike	Large	540	565	553
	Small	544	579	562
	Mean	542	572	557
		Frequency		
	N'hood	High	Low	Mean
Unwordlike	Large	504	518	511
	Small	498	557	527
	Mean	501	538	519

Table 1: Mean reaction times for subjects in the lexical decision experiment.

be presented with word and non-word stimuli, and that they should decide whether the stimulus was a word or a non-word and respond by pressing one of two buttons mounted on a small box in front of them. Subjects rested their two forefingers on the buttons with their dominant hand on the "word" key. They were instructed to respond as quickly as possible, while maintaining as high a level of accuracy as possible.

Subjects first completed 16 practice trials and then received 80 experimental trials preceded by two buffer items. Instructions and stimuli were presented on a V.D.U. screen controlled by a microcomputer that also recorded response latencies and errors. The stimuli were presented centre screen in lower case, and four different randomisations of the stimuli were used for each non-word condition.

Each stimulus appeared for 1 second. There was then a 1.5 second delay from stimulus offset until the beginning of the next trial. After 40 trials subjects were able to rest for as long as they wished before continuing with the remaining 40 trials.

Results

The mean reaction times for the correct word responses, and the average error rates were calculated separately across subjects and items, and each data set was subjected to an analysis of variance (ANOVA) with Scheffé tests being used to examine simple comparisons within the significant effects. The means for the subject data are shown in Table 1.

Analysis of the LDT data revealed a main effect of word frequency that was significant by subjects F_1 and items F_2 and, by $minF'$ ($F_1(1,22) = 30.77$, $p < 0.00001$; $F_2(1,36) = 24.20$, $p < 0.0001$, $minF'(1,57.09) = 13.55$, $p < 0.01$: higher frequency words were responded to faster than lower frequency words. The effect of neighborhood size was found to be significant by subjects but not by items,($F_1(1,22) = 5.92$,$p < 0.0236$, $F_2(1,36) = 3.44$, $p < 0.0716$,): words from larger neighborhoods were responded to faster than those from smaller neighborhoods.

The interaction between word frequency and neighborhood size was significant both by subject and item analyses, ($F_1(1,22) = 4.59$, $p < 0.0434$, $F_2(1,36) = 3.98$, $p < 0.0537$.

The effect of wordlikeness of nonword stimuli was significant by items and not by subjects,($F_1(1,22) = 2.12$, $p < 0.1591$, $F_2(1.36) = 30.77$, $p < 0.00001$: responses were made more quickly when nonword stimuli were more unwordlike. Wordlikeness did not interact significantly with any other variable. The effects of word frequency and neighborhood size are not changed significantly by making the words more unwordlike.

In the analysis of errors, the only significant result was a main effect of word frequency,($F_1(1,22) = 12.04$, $p < 0.0022$, $F_2(1,36) = 11.86$, $p < 0.0015$: more errors were made in responses to low frequency words than to higher frequency words.

Discussion

The experiment replicates the findings of Andrews (1989,1992). The results suggest lexical decision is sensitive to neighborhood size. The interaction of word frequency and neighborhood size shows the facilitating effect of neighborhood size is evident for low frequency words but non-existent for high frequency words.

The finding that wordlikeness did not change the effects of word frequency and neighborhood does not follow the pattern of results reported by Andrews (1989). Andrews reports a more extreme neighborhood effect when nonwords are more unwordlike, her comparison is however between two different experiments, where as here wordlikeness of foils was manipulated within the same experiment.

Experiment 2: immediate and delayed naming

Lexical access is not the only process operating in LDT, neighborhood size may have its locus of effect in the word/nonword discrimination rather than in lexical access. In order to establish whether it is lexical access or lexical classification which is being affected by neighborhood size, a naming study was conducted. Naming is thought to involve lexical access and some post lexical pronunciation processes, but not lexical classification, so the process it has in common with LDT is lexical access.

There is the chance that both LDT and naming could manifest an effect and lexical access still not be the source. In LDT neighborhood density facilitation could be due to lexical classification, and in naming, to processes of word production. To evaluate such a possibility a delayed naming naming condition was included. The delay between stimulus presentation and pronunciation ensures that processes involved in access and word recognition are completed before pronunciation. If the effect of neighborhood density exerted its influence on production processes it should still be evident in delayed naming, where as if it exerts its effect on lexical access it should have no effect on delayed naming.

Method

Subjects: The subjects were 24 different individuals from the same population as Experiment: 1.

Materials and design: Subjects participated in either an immediate or a delayed naming condition. The stimulus set was the same as that used in Experiment: 1 except that only word stimuli were used.

Procedure: For immediate naming the presentation procedure was identical to that of the LDT experiment subjects except that subjects were asked to respond by reading the words aloud. Reaction time was recorded from word onset by the triggering of a throat microphone worn by subjects on their larynx, so as to catch the very start of phonation.

In the delayed naming condition, subjects were told not to pronounce the word until a set of brackets appeared on the screen enclosing the word. The delay between stimulus presentation and the appearance of the brackets that served as the pronunciation cue varied randomly between intervals of 500, 800, and 110 ms, in order that subjects could not reliably anticipate its appearance.

Results

The mean response rates for correctly named words and the average error rates were calculated separately across subjects and items. Each data set was submitted to an analysis of variance (ANOVA). The means for the subject data are shown in table 2.

		Frequency		
	N'hood	High	Low	Mean
Immediate	Large	565	586	576
	Small	576	595	586
	Mean	570	591	581
		Frequency		
	N'hood	High	Low	Mean
Delayed	Large	422	424	423
	Small	439	416	428
	Mean	430	420	425

Table 2: Mean response rates for subjects in immediate and delayed naming.

The only significant effect was an interaction between word frequency and condition, which was significant by subjects, by items, and by *minF'*, ($F_1(1,22) = 12.95$, $p < 0.0016$; $F_2(1,36) = 6.56$, $p < 0.0147$, $minF'(1,57.546) = 4.354$, $p < 0.05$. Scheffé tests showed that in immediate naming frequency facilitates reaction times; high frequency words being responded to faster, whereas in delayed naming significantly faster reaction times were found for low frequency words. The interaction of word frequency and neighborhood size was not significant. The error analysis showed no significant results.

Discussion

The results of the naming study show no significant effect of neighborhood size on immediate or delayed naming. No support for the LDT result is found from the naming experiments. The only significant outcome was an effect of word frequency which differs between the two conditions: facilitating reaction times in immediate naming, but inhibiting those in delayed naming.

General discussion

Both LDT and immediate naming experiments produced significant word frequency effects, high frequency words being responded to faster than low frequency ones.

In LDT a facilitating effect of neighborhood size for low frequency words is found, just as in Andrews

(1989,1992) work.[1] The fact that neighborhood density effects appear in LDT with sub-lexical controls may be taken to suggest that words conspire on a lexical level to facilitate recognition. Controlling for bigrams, does not eliminate all sources of sub-lexical effects. Components such as trigrams or single letters remain possible origins of a sub-lexical influence, as does a sub-lexical checking mechanism. Facilitation at the lexical level of the word recognition process is inherently improbable. For a word to be recognised it must be discriminated from its lexical competitors: it must win out above the within-level inhibition. The competitiveness of the candidates will depend on their similarity to the target because they share features and so reinforce the presence of these features. If words are competing for recognition it is therefore more probable that only inhibition will operate on a lexical level and that activities of sub-lexical components will be both inhibitory and facilitatory. For example if the visual stimulus "CARD" is to be recognised then words such as "CARP" and "HARD" may also be active. At a lexical level for just one of these to be chosen as the response the others must be inhibited. At sub-lexical levels the "ARD" of "HARD" and the "CAR" of "CARP" may provide facilitation for "CARD" while the "H" and the "P" may inhibit the "CARD" target.

This description of sublexical inhibition and facilitation bears similarity to McClelland and Rumelhart's "gang effect" as already described. Within an IAM this effect will be most significant for low frequency words because words of high frequency start with a higher base level of activation. For high frequency words there is therefore less opportunity for reverberating letter activation from neighboring word units to occur.

The finding that neighborhood size can facilitate low frequency words appears to be strong evidence against any model that assumes a serial comparison of a lexical access code against an entry in lexical memory, as does Forster's. To accommodate such a finding would require serial search at a sub-lexical, letter or feature level. If the first stage in the formation of an access code involved the coding of these smaller units then codes for more frequent units would be found more quickly. Words with large neighborhoods are those made of more common sub-lexical units and so would be accessed faster than those words with smaller neighborhoods. The interaction of word frequency and neighborhood is still however unexplained by a serial model.

In the naming experiment no effect of neighborhood size was observed, a result contrary to the findings of Andrews, who found that the effect of neighborhood size was significant for low, but not for high frequency words.

Jared, McRae and Seidenberg (1990) among others, have shown the importance of phonology in naming tasks, something which does not appear to be so important in LDT. It could be that while in LDT orthographic neighbors are the source of the neighborhood effect, in the naming task variables which also concern pronunciation such as the relative frequencies of friends and enemies (Jared et al. 1990) are more important to recognition.

The present experiments provide further support for the claim that at least in LDT orthographic neighborhoods can conspire to facilitate a low frequency word's recognition. This facilitation occurs even when bigram frequencies are controlled. Whether this is also true for naming responses remains to be firmly established.

Conclusion

The experiments show that in some situations a target word can be facilitated by the existence of orthographic neighbors. This should not however be taken to imply that words are conspiring on a lexical level of representation. Although a words neighbors are the most similar lexical entries it is their shared sub-lexical components which produce the similarity. It is therefore likely to be the shared sub-lexical components of neighbors which are able to facilitate a words recognition.

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[1]The LDT results appear fast when compared to those of Andrews, especially for low frequency words. The source of this difference could be neighborhood size. Andrews reports a mean small neighborhood of 3.5 and a large one of 11.65. The means for neighborhood size in the present study were 7.9 for small and 20.25 for large. The finding that both support is that low frequency words are facilitated by larger neighborhoods. It follows therefore that in a study where larger neighborhoods are used reaction times will be faster.

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