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A New Technique for Visual Word Recognition Research: The Luminance Increment Paradigm.

Jonathan Grainger (1), Manuel Carreiras (2), and Manuel Perea (3)

[1] CNRS and Université de Provence,
Aix-en-Provence, France
[2] Universidad de La Laguna, Spain
[3] Universitat de València, Spain

Running head: The luminance increment paradigm.

Jonathan Grainger
Laboratoire de Psychologie Cognitive
Université de Provence,
29 Av. Robert Schuman,
13621 Aix-en-Provence,
France
grainger@up.univ-mrs.fr

ABSTRACT

A new paradigm for research in visual word recognition is used in an experiment manipulating word frequency, orthographic neighborhood, and list composition. The new paradigm shows standard effects of word frequency that interact with list composition: responses to high frequency words were faster in blocked high frequency lists than in mixed frequency lists, whereas low frequency words were responded to more slowly in pure as opposed to mixed lists. Low frequency words with many orthographic neighbors were responded to more rapidly than words with few orthographic neighbors, and this effect was not influenced by list composition. The results are discussed in terms of hypothesized lateral inhibitory and top-down excitatory processes operating during visual word recognition.

Progress in experimental psychology requires the development and testing of new methods as well as new theories. Furthermore, the interaction between data and theory that forms the core of all science, is facilitated by the availability of multiple measurement techniques. In one of the best studied micro-domains of psychological science, that of printed word perception, researchers already have a number of well-tested experimental tasks available, such as the lexical decision task, the word naming task, and a variety of perceptual identification tasks. Among the latter category, the progressive demasking task (PDM)[1] introduced by Grainger and Segui (1990) provided a distinct improvement over traditional perceptual identification tasks, in that there is a response time (RT) associated with each trial, and not just a correct/incorrect response classification. This task has proven useful in determining how word frequency and variations in orthographic similarity across words influence the process of printed word perception (e.g., Grainger & Jacobs, 1996).

However, one potential problem with the PDM technique is the possibility that the chosen mask (often a series of hash marks) may be more effective for certain letters. In view of this limitation, a variant of PDM was recently introduced by Rey, Grainger, Chesnet, Bijeljac-Babic, and Jacobs (1999; see also Rey, Jacobs, Schmidt-Weigand, & Ziegler, 1998). This variant, referred to as the luminance increment paradigm (LIP) involves gradually increasing the luminance value of the stimulus until it becomes identifiable by the participant. The stimulus is masked as soon as the participant responds in order to avoid anticipatory response strategies.

We initially expected this new paradigm to provide an improved, more noise-free version of PDM. However, one recent result (Rey, 1998) suggested that the two tasks might be differently sensitive to one particular variable. Both PDM and LIP show the standard word frequency effect (Grainger & Segui, 1990; Rey et al., 1999): high frequency words are responded to more rapidly than low frequency words. However, while effects of orthographic neighborhood tend to be inhibitory in PDM (Carreiras, Perea, & Grainger, 1997; Grainger & Segui, 1990; Grainger & Jacobs, 1996; van Heuven, Dijkstra, & Grainger, 1998), the recent study of Rey (1998) found facilitatory effects of this variable in LIP. Clearly, the fact that opposite effects of a given variable are observed in two different tasks implies that performance in these tasks does not reflect the operation of identical mechanisms.

The present study provides a direct test of the effects of number of orthographic neighbors in the LIP task, while also examining this task's sensitivity to list-composition. In a separate study (Perea, Carreiras, & Grainger, 1999), we have recently tested a set of stimuli carefully selected in terms of word frequency and orthographic neighborhood. Performance to these words has already been measured in several word recognition tasks including PDM. More specifically, in the PDM experiment, inhibitory effects of neighborhood density were observed, and these interacted with list-context. Blocked presentation greatly increased the inhibitory effects of this variable. Perea et al. argued that participants raise a response criterion based on activity in whole-word representations when stimuli are presented in blocked lists of words with many orthographic neighbors. This is hypothesized to reduce false identification errors while slowing RTs.

In the present study we test exactly the same set of stimuli in the LIP and compare the observed performance to that obtained previously in PDM. As in our previous study (Perea et al., 1999) the different stimulus categories were either presented in pure blocks or mixed blocks in order to investigate the operation of strategic factors in the new task.

Method

Participants. Forty-two psychology students from the Universidad de La Laguna took part in this experiment to fulfill a course requirement. All of them reported normal vision or vision that was corrected-to-normal and were native speakers of Spanish.

Design and Materials. A set of ninety-six disyllabic Spanish words were selected from the Spanish word pool (Alameda & Cuetos, 1995) as a function of word frequency (low-frequency, high-frequency) and neighborhood density (words with few neighbors vs. words with many neighbors, Coltheart, Davelaar, Jonasson, & Besner, 1977). All words were four or five letters long (forty-eight of four letters and forty-eight of five letters). A word was considered of high frequency when its written frequency was higher than 85 per two million words, whereas a word was considered of low frequency when its printed frequency was less than 15 per two million words. A word was considered from a large neighborhood when it had at least 8 orthographic neighbors, whereas a word was considered from a small neighborhood when it had less than 4 orthographic neighbors. In order to control for effects of neighborhood frequency within each frequency class, none of the high-frequency words had any higher frequency neighbors, whereas all the low-frequency words had at least one higher frequency neighbors. The characteristics of the words used in the experiment are presented in Table 1.

<Please insert Table 1 about here>

Two groups of 21 participants were tested. For each participant, there were two lists for each of the following conditions: 1) high-frequency, large neighborhood (HF-HN); 2) high-frequency, small neighborhood (HF-LN); 3) low-frequency, large neighborhood (LF-HN); 4) low-frequency, small neighborhood (LF-LN). In addition to the four pure lists, there were eight mixed lists composed of an equal number of words of the four categories. Assignment of words to conditions was arranged so that each word occurred both in a pure list and in a mixed list, but not for the same participant. Thus, if a word occurred in a pure list for Group 1, it occurred in a mixed list for Group B, and vice versa. Each experimental list contained twelve words. In order to establish a context for the words in each experimental block, four warm-up trials with the same characteristics as the block were also included. In this way, the participants would be familiar with the average difficulty of stimuli in each block. These warm-up trials were not considered in the analysis of the data. The words were presented in blocks of twelve items throughout (not including the warm-up trials). The 12 experimental lists were presented in a fixed semi-random order to all participants in one group (the other group receiving the reverse sequence), but within each list, a different random ordering of the twelve items occurred for each participant.

<u>Procedure</u>. The LIP involves gradually increasing the luminance value of the stimulus. This is done by increasing the RGB counters on successive cycles of a fixed duration. The precise rate of luminance increment is determined by the duration of the cycle (300 ms in the present study) and the increment value of the counters on each cycle. These are adjusted in pilot work such that the majority of responses fall between 1000 and 2000 ms (see Rey et al., submitted, for a more detailed presentation of the paradigm). The luminance increment increases on each cycle until participants press a response key indicating they have recognized a word. A pattern mask immediately replaces the stimulus at that point, and remains on the screen until the beginning of the next trial.

Response latencies were measured from the beginning of stimulus presentation (at the lowest luminance value) until the participant's response. Participants were instructed to focus their attention on the center of the visual display and to press the response key with the forefinger of their preferred hand as soon as they had recognized the word. They were instructed to type in the identified word using the keyboard of the computer. Pressing the return key then initiated the following trial. Participants were asked to carefully check that they had correctly typed the word they thought they had been presented before initiating the following trial.

Results

Incorrect responses and identification times greater than 2,000 ms (0.71%) were excluded form the latency analysis. Mean RTs on words were submitted to an Analysis of Variance (ANOVA), with Word frequency (high and low), Neighborhood density (high and low), Type of list (pure and mixed), and Group (list 1 and list 2) as factors. Group was included in the analysis to extract the variance due to the lists (Pollatsek & Well, 1995). Group was the only non repeated measures factor in the analysis by participants (F1). In the analysis by items (F2), word frequency, neighborhood density, and list were non repeated measures factors, whereas type of list was a repeated measures factor. The mean identification time and the error rate on the stimulus words in each experimental condition are displayed in Table 2.

<Please insert Table 2 about here>

RT analysis. The main effect of word frequency was significant, F1(1,40)=29.54, MSe=2641, p<.001; F2(1,88)=55.27, MSe=792, p<.001. The effect of neighborhood density was also significant, F1(1,40)=5.28, MSe=1812, p<.03; F2(1,88)=8.12, MSe=792, p<.01, as was the interaction between word frequency and neighborhood density, F1(1,40)=6.73, MSe=1511, p<.02; F2(1,88)=7.43, MSe=792, p<.02. The effect of neighborhood density was significant for low-frequency words, F1(1,40)=9.64, MSe=2046, p<.004; F2(1,88)=15.54, MSe=792, p<.001, but not for high-frequency words, both Fs<1.

The main effect of type of list was not significant, both Fs<1, but the interaction between word frequency and type of list was significant, F1(1,40) =12.72, MSe=2056, p<.002; F2(1,88)=27.33, MSe=693, p<.001. High-frequency words were responded to faster in the pure list than in the mixed list, $F1(1,40) =10.42$, $MSe=1770$, $p<.003$; $F2(1,88)=14.85$, $MSe=693$, $p<.001$; whereas low-frequency words were responded to faster in the mixed list than in the pure list, $F1(1,40)=5.13$, $MSe=1683$, $p<.03$; $F2(1,88)=12.53$, $MSe=693$, $p<.001$. The other interactions were not significant.

Error analysis. The effect of word frequency was significant, $F1(1,40)=10.01$, $MSe=19.3$, $p<.004$; $F2(1,88)=7.55$, $MSe=13.1$, $p<.008$. The effect of neighborhood density was not significant, both Fs<1. The interaction between word frequency and neighborhood density was significant in the analysis by participants, $F1 (1,40)=9.59$, $MSe=6.9$, $p<.004$; $F2(1,88)=2.60$, $MSe=13.1$, $p=.1108$. The effect of neighborhood density was significant for low-frequency words in the analysis by participants, $F1(1,40)=4.68$, $MSe=11.5$, $p<.04$; $F2(1,88)=2.17$, $MSe=13.1$, $p=.14$, but not for high-frequency words, $F1(1,40)=2.40$; $F2<1$. None of the interactions with type of list were significant.

Discussion

In line with the results reported by Rey (1998), the present study observed facilitatory effects of neighborhood density for low frequency words tested in the new luminance increment paradigm (LIP). These neighborhood density effects were not influenced by type of presentation (blocked versus mixed lists). On the other hand, the effects of word frequency were significantly larger in pure lists than mixed lists. High frequency words were responded to faster in pure blocks of high frequency words compared to mixed blocks of high and low frequency words, whereas low frequency words were responded to more slowly in pure blocks of low frequency words. One general explanation for this frequency blocking effect is that participants lower a given response criterion in blocked lists of words that are easy to identify (i.e. high frequency words), and raise the criterion in blocked lists of difficult (i.e. low frequency) words (Lupker, Brown, & Colombo, 1997). One means of implementing such a mechanism would be to adjust response criteria on a trial-by-trial basis in an attempt to reduce RTs while maintaining an acceptable level of accuracy (Perea et al., 1999).

There are two main differences between the pattern of data obtained in the present study with the LIP and the pattern observed to the same set of stimuli in PDM by Perea et al. (1999). First, facilitatory effects of orthographic neighborhood are obtained in LIP, while these effects are inhibitory in PDM. Second, the effects of orthographic neighborhood did not interact with list composition in LIP but did interact in PDM (pure list presentation exaggerated the inhibitory effects of orthographic neighborhood in the Perea et al. study). Perea et al. interpreted the list composition effects obtained in PDM as resulting from strategic modification of a word-specific response criterion used to perform this task (see Grainger & Jacobs, 1996). This criterion is adjusted as a function of the average RTs and error rates to stimuli in a given list. Both word frequency and orthographic neighborhood are hypothesized to determine speed and accuracy of responding with this criterion: the higher the frequency and the smaller the number of orthographic neighbors, the better the performance. In this way, both frequency and orthographic neighborhood are influenced by list composition.

There are at least two ways of capturing the different pattern of results obtained in the LIP and PDM tasks. One is to argue that the LIP is a better reflection of "normal" word recognition, and that the use of a pattern mask in the PDM technique encourages guessing behavior assumed to be the cause of inhibitory effects of orthographic neighborhood obtained with this task (Forster & Shen, 1996). There are a number of reasons why this solution appears improbable to us. One of these is the fact that pure list presentation exaggerates the effects of orthographic neighborhood (Perea et al., 1999). One would expect such a manipulation to reduce the range of possible guesses (to only low frequency words, for example) and therefore diminish the influence of incorrect guesses.

Alternatively, one could argue that inhibitory effects of orthographic neighborhood are only observed in tasks that force participants to respond on the basis of activity in whole-word representations (Grainger & Jacobs, 1996). Here we advance the hypothesis that the LIP encourages responses based on activity in letter representations (letter-level readout), whereas the PDM technique encourages word-level readout. This hypothesis is based on the fact that a word's component letters are more sensitive to masking influences than the whole-word itself (the word superiority effect). In a cascaded activation model with letter and word representations (McClelland & Rumelhart, 1981), on presentation of a stimulus word activation builds up and reaches asymptote in letter representations faster than in word representations. Thus, when no masking stimulus intervenes, the activation of letter representations would be a good cue that there is enough accumulated evidence to formulate a correct response.[2] However, when stimulus presentation is mixed with a pattern mask, as in the PDM technique, low-level feature and letter representations are reset on each presentation of the masking stimulus, hence only activity in word representations can serve as a good cue for accurate performance.

A combination of word-level and letter-level response criteria can therefore account for the pattern of results obtained with the LIP. High frequency words will predominantly give rise to readout via a whole-word response criterion (the more frequent a word is the faster its representation will reach a given activation level), whereas letter-level readout will occur more often for low-frequency words. In this case, responses to low-frequency words would be affected by number of orthographic neighbors via word-to-letter feedback. The letter representations in words with large numbers of orthographic neighbors would have more rapidly rising activation curves. However, since words with large numbers of orthographic neighbors generally suffer the most lateral inhibition at the word level, the activation level of their whole-word representations tend to rise more slowly compared to words with small numbers of orthographic neighbors. Letter-level readout could therefore compensate for inhibitory processes operating at the whole-word level.

Thus, the facilitatory effects of neighborhood density observed in the LIP would be attributed to top-down influences from word representations to their component letters (Andrews, 1989; 1992), whereas the inhibitory effects of neighborhood density observed in the PDM would be attributed to competitive influences across simultaneously activated word representations (Grainger & Jacobs, 1996). If this interpretation is correct, it would suggest that the inhibitory effects of higher frequency neighbors probably occur late in word processing, as competition is resolved to enable unique word identification (see Perea & Pollatsek, 1998, for some evidence for this from eye-movement recordings). Facilitatory effects of neighborhood density, when they are observed in tasks requiring unique word identification, would reflect top-down reinforcement of sublexical processing from whole-word representations.

The question of how a given word's orthographic similarity to other words influences the recognition of that word, is likely to remain a critical issue well into the next century. Applying various experimental techniques, such as the luminance increment paradigm, to study the effects of various measures of similarity (e.g., Andrews, 1997; Ziegler & Perry, 1998) should provide the critical evidence to help complete our understanding of these important phenomena.

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Author note

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Footnotes

1. In the progressive demasking task stimulus presentation is alternated with a pattern mask. The duration of the stimulus is increased and the duration of the mask decreased in cycles of approximately 300 ms until the participant hits a response key indicating that (s)he has identified the stimulus.

2. The general idea is that participants can also (i.e., in addition to lexical information) use some form of nonlexical estimation of stimulus quality in order to determine when they have sufficient information to generate an accurate response at the earliest possible moment. Within the specific framework of the Interactive Activation model (McClelland & Rumelhart, 1981), this is most easily implemented in terms of response read-out based on letter-level activation.

Table 1.
Characteristics of the words tested in the Experiment

	Word Frequency	Number of Neighbors
HF-LN:	319 (88-793)	1.3 (0-3)
HF-HN:	321 (114-866)	11.2 (8-19)
LF-LN:	6 (1-13)	1.7 (1-3)
LF-HN:	7 (2-14)	10.9 (8-16)

Note: The ranges are given between brackets. HF=high frequency, LF=low frequency, HN=large number of neighbors, LN=small number of neighbors. Frequency expressed as number of occurences in a two million corpus.

Table 2.

Mean identification times (in ms) and percent errors (in parentheses). The list blocking effect is calculated by subtracting pure list RT from mixed list RT for each category of word.

	Type of List		
	Pure	Mixed	Mixed-Pure
HF-LN:	1138 (1.1)	1164 (0.0)	26 (-1.1)
HF-HN:	1143 (1.1)	1159 (1.3)	16 (0.2)
LF-LN:	1200 (3.4)	1185 (2.5)	-15 (-0.9)
LF-HN:	1177 (1.5)	1164 (2.1)	-13 (0.6)

Note. HF=high frequency, LF=low frequency, HN=large number of neighbors, LN=small number of neighbors.