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ScienceDirect
International Journal of Psychophysiology 65 (2007) 132–140
INTERNATIONAL JOURNAL OF PSYCHOPHYSIOLOGY
www.elsevier.com/locate/ijpsycho

Pupillary responses during lexical decisions vary with word frequency but not emotional valence

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Received 10 October 2006; received in revised form 12 April 2007; accepted 12 April 2007
Available online 19 April 2007

Abstract

Pupillary responses were examined during a lexical decision task (LDT). Word frequency (high and low frequency words) and emotional valence (positive, neutral and negative words) were varied as experimental factors incidental to the subjects. Both variables significantly affected lexical decision performance and an interaction effect was observed. The behavioral results suggest that manipulating word frequency may partly account for the heterogeneous literature findings regarding emotional valence effects in the LDT. In addition, a difference between high and low frequency words was observed in the pupil data as reflected by higher peak pupil dilations for low frequency words, whereas pupillary responses to emotionally valenced words did not differ. This result was further supported by means of a principal component analysis on the pupil data, in which a late component was shown only to be affected by word frequency. Consistent with previous findings, word frequency was found to affect the resource allocation towards processing of the letter string, while emotionally valenced words tend to facilitate processing.

Keywords: Pupillary response; Lexical decision; Word frequency; Positive, neutral, negative words; PCA

1. Introduction

The lexical decision paradigm is often used to determine the variables which affect the processes underlying word recognition. In the lexical decision task (LDT), subjects have to judge the lexicality of a presented letter string, the task being to decide as quickly as possible whether the string is a word or not a word. The time needed to solve this task, e.g., the speed of extracting relevant stimulus information from a letter string to recognize it as a word, is used as a measure of lexical access (Jacobs and Grainger, 1994). Since several studies provided evidence that lexical decisions can be executed before the letter string has been evaluated consciously, the variables that affect lexical decision performance can be seen as factors determining implicit information processing (e.g., Balota and Chumbley, 1984; Grainger and Jacobs, 1996).

One of the variables known to cause variation in LDT response times is word frequency, a measure of the frequency with which a word is used in a language (Balota and Chumbley, 1984; Gernsbacher, 1984; Monsell et al., 1989). When comparing high frequency with low frequency words in the LTD, high frequency words are recognized faster and with higher accuracy, elicit shorter fixations in reading as indicated by eye-movement research (Rayner and Duffy, 1986), and affect components of event-related potentials (Dambacher et al., 2006; Hauk and Pulvermüller, 2004; Rugg, 1990; Sereno et al., 1998), where the early components in a time window between 132 ms (Sereno et al., 1998) and 200 ms are seen as an upper time limit of lexical access (Hauk and Pulvermüller, 2004). Its reliable findings across different tasks and methods have made word frequency one of the key contributors to motivate models of word recognition (Coltheart et al., 2001; Grainger and Jacobs, 1996; Plaut and Booth, 2000). A common assumption from these models is that high frequency words can be recognized as a whole word whereas low frequency words demand additional analysis (e.g., phonological processing; Coltheart et al., 2001; for a further discussion see Barber and Kutas, 2007). Accordingly, the effects of word

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doi:10.1016/j.ijpsycho.2007.04.004

frequency have been found to affect different time windows during lexical processing, e.g., an early window around 200 ms post-stimulus presentation and a late time window between 300 and 500 ms post-stimulus presentation. Recently it was argued that the latter time window reflects post-lexical processing (Hauk and Pulvermüller, 2004). Moreover, lexico-semantic variables have been shown to affect the processing of low frequency words to a higher degree and at later processing stages (Dambacher et al., 2006; Hauk et al., 2006). Recent results from Hauk et al. (2006) suggest that word frequency might even have an effect before lexical access takes place. By showing that parallel effects of word frequency and lexico-semantic features can be observed in parallel in later time windows, the authors demonstrate that word frequency and lexical representations are accessed consecutively.

Common to most models of word recognition is the idea that visually presented letter strings do initially activate word representations in the mental lexicon which share either orthographic or phonological features. The consideration of effects of semantic information mainly includes the activation of semantic nodes via a relational network, where semantic information is supposed to enhance or inhibit subjects' performance in visual word recognition at a later processing stage (Plaut et al., 1996). An example of the influence of semantic information is the effect that emotionally valenced words have. Subjects tend to respond faster and with fewer errors in the LDT to emotionally valenced words than to neutral words, though this issue remains controversial (Bradley et al., 1994; Challis and Krane, 1988; Kuchinke et al., 2005; Matthews and Southall, 1991; StrauB, 1983; Williamson et al., 1991; Windmann et al., 2002). While Challis and Krane (1988) reported speeded responses for both positive and negative words, Kuchinke et al. (2005) found that only positive words showed the processing advantage, a result which is in accordance with a meta-analysis of seven LDT studies where no difference in the performance between negative and neutral words was observed (Siegle et al., 2002). It is important to note that all these studies differ in the way they controlled their stimulus material for factors known to affect lexical decision times.

These heterogeneous results in the behavioral data are accompanied by recent imaging results which present evidence for differences in the implicit processing of verbal affective material. In a functional magnetic resonance imaging (fMRI) study on lexical decisions using well-controlled stimulus material, Kuchinke et al. (2005) found a reliable facilitating effect of positive words (compared with neutral and negative words) on error rates and reaction times in both a behavioral pilot study and the subsequent fMRI study. Moreover, although negative words and neutral words could not be distinguished in their behavioral data, distinct brain regions were identified and associated with the processing of positive words (anterior pre-frontal cortex) and negative words (right dorsolateral pre-frontal cortex). It has previously been shown that these regions belong to a network supporting semantic processing, and the findings of Kuchinke et al. (2005) suggest that emotional valence further sub-divides this network.

Different event-related potential (ERP) studies reported modulation of ERP data in a time window of 100–400 ms after stimulus onset using the LDT paradigm (Williamson et al., 1991; go/nogo LDT: Ortigue et al., 2004) or using sub-liminal stimulus presentation (Bernat et al., 2001) which is in accordance with theories that propose an early pre-conscious stimulus evaluation along the emotional valence dimension. In their 'affective primacy hypothesis' Murphy and Zajonc (1993) describe a pre-attentive memory system which categorizes incoming information depending on whether this information is positive or negative. It is proposed that this process may occur at an early stage of perception (Anderson and Phelps, 2001; Bargh, 1992; Windmann et al., 2002). For example, using a LDT with sub-liminal stimulus presentation conditions Windmann et al. (2002) reported evidence of pre-lexical effects of emotionally negative information. Both dependent signal detection measures, the 'WORD'–'NONWORD' discrimination performance and the bias to classify a stimulus as a 'WORD', showed a significant enhancement for negative compared with neutral words, leading the authors to conclude that any visually presented verbal stimulus is initially evaluated for its emotional significance at a pre-lexical level.

In the present study the variables of word frequency and emotional valence are varied as independent factors in a lexical decision experiment. According to the model proposed by Kitayama (1990), which makes assumptions about an interaction between emotion and word frequency in word recognition, evaluative processes as well as either phonological, orthographic or morphological processes operate in parallel. Hence, emotional significance may facilitate word recognition when subjects have to process a letter string at an early processing stage, however only high frequency words benefit from the perceptual enhancement effect.

In addition to behavioral measures (reaction times and error rates), subjects' pupillometric measures were examined. Task-evoked pupillary responses have reliably been shown as sensitive to cognitive processing demands during a task (Beatty and Kahneman, 1966; Granholm et al., 1996; Just and Carpenter, 1993; Nuthmann and van der Meer, 2005) and were suggested to represent a summative index of the brain activity associated with performance in cognitive and emotional tasks (Beatty, 1982). The pupil starts to dilate within the first few hundred milliseconds after the onset of a cognitive demand. The peak pupil dilation correlates with the amount of cognitive load associated with a memory task (Beatty and Kahneman, 1966) or emotional processing (Hess, 1965; Janisse, 1974). The contribution of pupillary responses to the examination of emotional processing remains controversial. In an early study, Hess (1965) reported pupil dilations when looking at positive pictures and pupil constrictions for negative material (also see Mudd et al., 1990). On contrast, later studies found pupil dilations for emotional pictures (independent of their actual valence) compared with neutral stimuli (see Janisse, 1974; Steinhauer et al., 1983; Partala and Surakka, 2003 using emotional sounds). These results suggest that the pupil dilations are associated with the resources allocated to the processing of emotional stimuli rather than being related to the emotional valence of the stimuli.

Siegle et al. (2001) examined pupillary responses in a lexical decision task using emotionally valenced words when comparing depressed and non-depressed subjects, but did not report task-evoked peak pupil dilation measures. Instead a principal