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Decision-related factors in pupil old/new effects: Attention, response execution, and false memory

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ABSTRACT

In this study, we investigate the effects of decision-related factors on recognition memory in pupil old/new paradigms. In Experiment 1, we used an old/new paradigm with words and pseudowords and participants made lexical decisions during recognition rather than old/new decisions. Importantly, participants were instructed to focus on the nonword-likeness of presented items, not their word-likeness. We obtained no old/new effects. In Experiment 2, participants discriminated old from new words and old from new pseudowords during recognition, and they did so as quickly as possible. We found old/new effects for both words and pseudowords. In Experiment 3, we used materials and an old/new design known to elicit a large number of incorrect responses. For false alarms ("old" response for new word), we found larger pupils than for correctly classified new items, starting at the point at which response execution was allowed (2750 ms post stimulus onset). In contrast, pupil size for misses ("new" response for old word) was statistically indistinguishable from pupil size in correct rejections. Taken together, our data suggest that pupil old/new effects result more from the intentional use of memory than from its automatic use.

1. Introduction

Recognition memory has received much attention over the past decades and has yielded a number of important insights into human cognition. For example, we know that stored representations in memory (such as word frequency and the emotional valence of words), strength of encoding, response confidence, and retrieval orientation through the use of specific filler materials affect recognition and recollection (Beisteiner et al., 1996; Curran, 1999, 2004; Gardiner and Java, 1990; Rugg, 1990; Rugg and Doyle, 1992; Rugg et al., 1995; Van Strien et al., 2009; Wilding, 2000; Wilding and Rugg, 1996; Xu et al., 2015; Zawadzka et al., 2017). Much of what we know has come from studies using event-related brain potentials (ERPs, see Rugg and Curran, 2007; Yonelinas, 2002 for reviews). In these studies, researchers have measured mass neural activity at the scalp of a participant, while the participant performed a task. ERP investigations – complemented by behavioral measures – have led to the proposal of competing models, which we can group into dual-process and single-process models of recognition memory. Proponents of dual-process models assume that recognition memory involves an automatic (and somewhat unconscious) activation or retrieval process, related to familiarity, and a more conscious process of activation or retrieval, related to recollection (see Yonelinas, 2002 for a review). Proponents of single-process models, in contrast, assume that there is only one process that can unambiguously be linked to recognition memory, with the other process being related to conceptual priming (Olichney et al., 2000; Paller et al, 2007; Voss and Paller, 2009; Voss and Federmeier, 2011) or decisional factors (Finnigan et al., 2002).

Evidence in favor of both models has been presented in the literature and this evidence has come from manipulations of the tested materials and the manipulation of the implemented task. For example, data supporting dual-process models have often come from remember/know paradigms, in which participants discriminate previously studied, old stimuli from previously unstudied, new stimuli on the basis of familiarity ("know" responses) or recollection ("remember" responses). It has been shown that ERP old/new effects are larger for "remember" than "know" responses, but only for the ERP component associated with recollection (the late positivity component, LPC). Roughly equally large old/new effects have typically been registered for the ERP component associated with familiarity (the frontal negativity component, FN400). However, there is also evidence that "know" responses yield no old/new effects at all when conceptually impoverished materials are used (Voss and Paller, 2009). This finding supports the claim that what some researchers assume to reflect familiarity processes might in fact reflect conceptual priming. Regardless of what model researchers will ultimately agree on, inspection of the many studies that have been

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conducted in the field stresses the importance of systematically and carefully testing both properties of the experimental task and properties of the experimental materials.

More recently, recognition memory has also entered the field of pupillometry. Pupillometry describes the study of the size of the pupil, with the pupillary light reflex being the strongest predictor of pupil size. However, there is also a somewhat long history of the study of task-evoked pupillary responses, in particular in cognitive psychology and psychophysiology. Unlike the pupillary light reflex, task-evoked responses of the pupil have typically been associated with processing load, attention, detection, and memory (see Beatty and Lucero-Wagoner, 2000 for a review). One great benefit of pupil measures over, for example, neurophysiological markers such as ERPs or the measure of magnetic fields through magneto-encephalography (MEG), is that pupil size can comparably easily be assessed for populations such as young children and patients. In addition, eliciting pupil size is arguably much easier and less costly than eliciting ERPs or MEGs.

The basic finding in recognition memory using pupillometry, first reported by Võ et al. (2008), is that stimuli that are recognized from a preceding study phase lead to larger pupils than stimuli that participants correctly judge to be new. This pupil old/new effect has been replicated in a number of experiments and has led to several conclusions about the link between pupil size and recognition memory (Brocher and Graf, 2016; Heaver and Hutton, 2011; Kafkas and Montaldi, 2012, 2015; Kamp and Donchin, 2014; Otero et al., 2011; Papesh et al., 2012). For example, Kafkas and Montaldi (2012, 2015) suggested that the pupil dissociates familiarity from recollection. Using a remember/know paradigm, the authors found that the pupil dilates more for "remember" than "know" responses. Thus, just like proponents of dual-process models of recognition memory claim that there are different signatures of familiarity and recollection processes in ERPs, Kafkas and Montaldi suggest that there are also two different signatures in the size of the pupil. However, this strong conclusion might be premature considering that we know comparably little about what might affect pupil size in old/new paradigms in addition to the recognition of previously studied items. In other words, although there is good consensus in the field that pupil size can distinguish between old and new stimuli, what other parameters might also affect the size of the pupil in an old/new experiment, and therefore potentially have affected the data reported for previous experiments, is rather unclear. In particular when we aim at bridging ERP and pupil old/new effects, it is essential to determine the boundary conditions for pupil old/new effects, just like such boundary conditions have been targeted in ERP investigation (see e.g., Voss and Paller, 2009). Indeed, a number of parameters have been shown to reliably affect pupil size, with memory processing being only one of them (see Beatty, 1982a, 1982b; Beatty and Lucero-Wagoner, 2000 for reviews).

Another benefit of a good understanding of pupil old/new effects is that it bears the potential for contributing to the growing body of studies that investigate the locus coeruleus-norepinephrine system (LC-NE). A systematic study of memory retrieval and its link to pupil size might shed some light on the various functions of the LC-NE system with respect to memory processing, attention, decision-making, and fluent intelligence (Aston-Jones and Cohen, 2005; Aston-Jones et al., 2000; Gabay et al., 2011; Kamp and Donchin, 2014; Nieuwenhuis et al., 2005; Privitera et al., 2010; Tsukahara et al., 2016). The most critical finding is that pupil size correlates positively with activity in the LC-NE system (Joshi et al., 2016). We then propose that understanding the precise link between pupil size, on the one hand, and memory, attention, and decision-related processes, on the other, can provide important, albeit indirect, evidence for how activity in the LC-NE system affects human behavior.

In this paper, we zoom-in pupil old/new effects and ask to what extent they interact with decision-related factors. The three factors under investigation are focus of attention, response execution, and false memory. We opted for these factors because, although there is some evidence for their involvement in pupil old/new effects (Brocher and Graf, 2016; Heaver and Hutton, 2011; Kafkas and Montaldi, 2015; Otero et al., 2011; Montefinese et al., 2013), they have never been investigated systematically within the broader scope of decision-making. We ask three questions. First, to what extent do pupil old/new effects depend on participants' focus of attention? Second, to what extent does response execution affect pupil old/new effects? Third, to what extent do pupil old/new effects occur when participants respond incorrectly? The first two research questions were addressed in Experiments 1 and 2 and involved words and pseudowords in an old/new paradigm consisting of a study and a recognition phase. In Experiment 1, participants made lexical decisions during recognition while focusing on the nonword-likeness of the presented stimuli. In Experiment 2, participants engaged in speeded old/new decisions, so that response execution fell within the window in which pupil size was recorded. In Experiment 3, we aimed at eliciting large numbers of false alarms and misses, allowing us to analyze pupil old/new effects for trials where participants responded incorrectly.

2. Experiment 1

Kafkas and Montaldi (2012, 2015) recently claimed that pupil size could be used to distinguish familiarity and recollection processes of recognition memory. They found that the pupil dilates more for pictures that participants recalled from study (recollection) than for pictures that participants felt they had encountered during study (familiarity). However, Brocher and Graf (2016, 2017) objected that these results might have come from specific properties of the remember/know task the authors used. Indeed, for materials known to distinguish familiarity and recollection in ERPs (lexicality: Beisteiner et al., 1996; Curran, 1999; Gardiner and Java, 1990; word frequency: Rugg, 1990; Rugg and Doyle, 1992; Rugg et al., 1995; valence: Van Strien et al., 2009; Xu et al., 2015), Brocher and Graf (2016) failed to find any evidence for a familiarity/recollection distinction in the size of the pupil.

Brocher and Graf (2016), then, suggested that pupil size during stimulus recognition in an old/new experiment is likely to reflect strength of memory trace and that task demand and response behavior affect the recruitment of that trace. When the authors used a typical old/new paradigm (consisting of a study phase and a subsequent recognition phase) with legal words and pseudowords (letter strings with no long-term representation in semantic memory), they found reliable old/new effects with no difference between the two kinds of stimuli. However, when the authors changed the task from old/new discriminations to word/pseudoword discriminations ("yes" for legal word, "no" for pseudoword), they elicited old/new effects only for the legal words when participants had ample time to respond (their Experiment 4), and no old/new effects at all when participants were instructed to respond as quickly as possible (their Experiment 5).

Brocher and Graf proposed the focus-of-attention hypothesis. They surmised that pupil old/new effects, while emerging from strength of memory trace, are critically linked to a participant's focus of attention and, more generally, to task demand. They argued that strength of memory trace in general and old/new effects in particular vary to the degree that (a) a participant pays attention to the task-relevant properties of the stimuli and (b) the task allows for the memory trace to be recruited or activated by the participant. In a typical old/new paradigm, old/new effects are expected because participants presumably attend all stimuli equally well (since their task is to memorize letter strings for later recognition). In a lexical decision task, however, attention typically falls on the word-likeness of the presented stimuli, not on their nonword-likeness. Thus, legal words, by virtue of having a long-term memory representation, are likely to enter a participant's focus of attention more quickly and remain longer within that focus than pseudowords, which lack a long-term memory representation. This, in turn, should allow participants to recruit the memory trace of words more quickly than the memory trace of pseudowords.[1] Finally,