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Pupil dilation in response preparation

Sofie Moresi [a,*], Jos J. Adam [a], Jons Rijcken [a], Pascal W.M. Van Gerven [b], Harm Kuipers [a], Jelle Jolles [b]

[a] Department of Movement Sciences, Maastricht University, PO Box 616 6200 MD Maastricht, Netherlands
[b] Department of Psychology, Maastricht University, PO Box 616 6200 MD Maastricht, Netherlands

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Abstract

This study examined changes in pupil size during response preparation in a finger-cuing task. Based on the Grouping Model of finger preparation [Adam, J.J., Hommel, B. and Umiltà, C., 2003b. Preparing for perception and action (I): the role of grouping in the response-cuing paradigm. Cognitive Psychology. 46, (3), 302–358.; Adam, J.J., Hommel, B. and Umiltà, C., 2005. Preparing for perception and action (II) Automatic and effortfull Processes in Response cuing. Visual Cognition. 12, (8), 1444–1473.], it was hypothesized that the selection and preparation of more difficult response sets would be accompanied by larger pupillary dilations. The results supported this prediction, thereby extending the validity of pupil size as a measure of cognitive load to the domain of response preparation.

Keywords: Response preparation; Pupil dilation; Reaction time; Cuing; Cognitive load

1. Introduction

Preparing to act facilitates motor performance. The underlying processes of this performance enhancement have been studied by means of response-cuing paradigms, in which cues provide information about some, or all, of the required response parameters before the actual target stimulus appears. Thus, cues in response-cuing paradigms allow and induce a process of response preparation that facilitates motor performance. For instance, in the finger-cuing paradigm developed by Miller (1982), a visual cue signal indicates a subset of two possible finger (i.e., key press) responses out of a total of four, thus allowing the selection and preparation of a subset of finger responses. The robust finding from this paradigm is that, given sufficient preparation time, informative cues substantially shorten reaction time (RT) relative to an uncued condition (Reeve and Proctor, 1990; Adam et al., 2003b). The present study extends the numerous chronometric studies on response preparation by examining its effect on a psychophysiological measure, pupil dilation, with the purpose of further delineating its underlying mechanisms.

The cognitive pupillary response or the task-related change in pupil size has been shown to be a reliable measure of processing load and resource allocation, with larger pupil dilation reflecting greater processing load or mental effort. This has been established in many studies of language processing, perception, memory, complex reasoning, and attention, which all reported larger pupil dilations for more difficult tasks (Andreassi, 2000; Beatty and Lucero-Wagoner, 2000; Jennings and Van der Molen, 2005). In the present study, we used the sensitivity of the pupillary response to task complexity to test a theoretical account (Adam et al., 2003b, 2005) of an interesting phenomenon typically observed in the finger-cuing task, namely a pattern of differential preparation benefits. Before explaining this phenomenon and the proposed account, we first describe the finger-cuing task in detail.

In the finger-cuing task (Miller, 1982), participants are forewarned by a visual cue signal about a particular subset of possible finger responses. Typically, they respond to horizontally arranged stimuli by spatially compatible key press responses with the index and middle fingers of both hands placed

* Corresponding author. Tel.: +31 43 3881394; fax: +31 43 3670972.
E-mail address: sofie.moresi@bw.unimaas.nl (S. Moresi).

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adjacently. In the present study, the visual display consists of four white boxes on a computer monitor, in which the cue and target signals were presented (see Fig. 1). At the start of a trial, a neutral warning stimulus ("+" sign) appeared between the two center boxes for 1 s. Then, the cue signal was presented for 2 s by coloring two boxes grey. Following the cue signal, the target stimulus was presented by making one of the two grey boxes black, thus indicating the required finger response. The 2-s time interval between onset of the cue and onset of the target stimulus is called the preparation interval, as it reflects the amount of time participants have to selectively prepare the two finger responses indicated by the cue before the appearance of the target. The functional significance of the cue is that it transforms the basic four-choice task into a two-choice task. Four cue or preparation conditions can be distinguished (Fig. 1). In the *hand-cued* condition, the cue specifies two fingers on the same hand (e.g., the left-middle and left-index fingers). In the *finger-cued* condition, the cue specifies the same finger on two hands (e.g., the left-index and right-index fingers). In the *neither-cued* condition, the cue specifies different fingers on two hands (e.g., the left-index and right-middle fingers). These three preparation conditions are called the "cued" conditions. Also, an *uncued* control condition is included. Here, the cue does not provide advance information about the upcoming response (all four boxes turn grey), thus precluding selective response preparation. In other words, the uncued condition leaves the basic 4-choice task unaltered and, thus, is a control or baseline condition, against which the effects of the "cued" conditions can be evaluated. Since RTs in a 2-choice task are substantially shorter than RTs in a 4-choice task (Hick, 1952; Hyman, 1953), cue effectiveness is inferred from a significant RT advantage or benefit for the 2-choice "cued" conditions (i.e., hand-cued, finger-cued, and neither-cued) over the control, 4-choice (uncued) condition. Thus, with longer preparation intervals (1000 ms and more), hand-cued, finger-cued, and neither-cued conditions all show substantially shorter RTs than the uncued condition, reflecting the operation of selective preparation.

A strong and often replicated observation in the finger-cuing paradigm is a pattern of differential cuing benefits: RTs are shortest for the hand-cued condition, longest for the neither-cued condition, and intermediate for the finger-cued condition, suggesting an ordering in terms of preparation difficulty (Reeve and Proctor, 1990; Adam et al., 2003b). It should be noted, however, that this pattern of differential cuing benefits only emerges with short preparation intervals (i.e., intervals less than about 1.5 s). When the preparation interval is extended to 2 s or more, the three cued conditions often show comparable RTs. Thus, certain pairs of responses can be selected and prepared more quickly than others, with small or no differences between the pairs given sufficiently long preparation time.

A recent account of the pattern of differential cuing benefits is the Grouping Model (Adam et al., 2003b, 2005), which is an extension of the salient-features coding principle (Reeve and Proctor, 1990). The key idea of the Grouping Model is that the individual elements of multi-element visual displays and multi-element response arrays are not processed independently but are preattentively organized or "grouped" according to low-level grouping factors that may depend on stimulus-driven (e.g., Gestalt principles) and response-related factors (e.g., inter-response dependencies). Thus, when presented with an array of four horizontally aligned potential target locations (centered on a person's midline), left-right (i.e., hand-) cues are easily encoded into left or right visual groups based on the Gestalt principle of proximity. In addition, such left-right cues are also easily encoded into left-right response groups, which involve the two fingers on the left or right hands. No other set of cues affords such simple, strong perceptual–motor subgroups, as both inner-outer (i.e., finger-) cues and alternate (i.e., neither) cues require binding separate items across the midline. The outcome of this is that left-right or hand-cues can activate responses in a fast, bottom-up manner while the other cues must activate responses in a slower, top-down manner. Left-right cues may also cause automatic shifts of attention to the cued locations while bilateral cues may require volitional shifts of attention (Adam et al., 2003a, 2005). Together, these perceptual, motor, and attentional factors produce the left-right or hand-cued advantage.

There are now several experiments that support the Grouping Model. For example, the advantage of left-right or hand-cues can be reduced, and even eliminated, if the distance between the two inner cues is greatly reduced (i.e., making the inner cues the easiest to encode) (e.g., Adam et al., 2003a, Experiment 2; Reeve et al., 1992, Experiment 2) or if the four responses are mapped onto a single hand (i.e., eliminating the response grouping present with two fingers on two hands) (e.g., Adam et al., 2003a; Proctor and Reeve, 1986). Additionally, no-onset

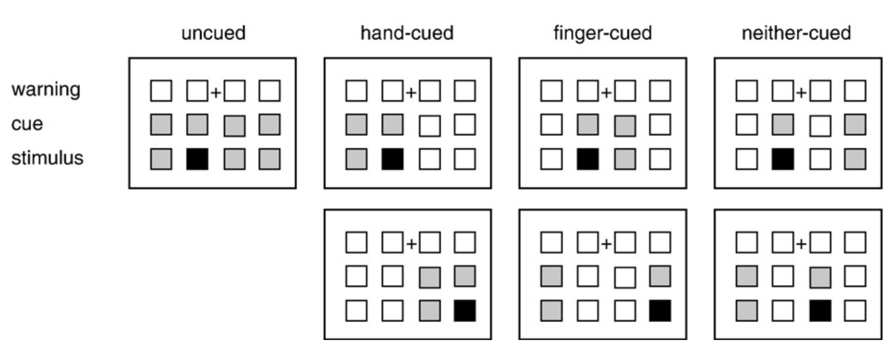

Fig. 1. A schematic representation of the finger-cuing task. Cue and target stimuli are presented overlaid and not in separate rows.