International Journal of Psychophysiology 79 (2011) 280–286

Contents lists available at ScienceDirect

International Journal of Psychophysiology

journal homepage: www.elsevier.com/locate/ijpsycho

Response preparation with adjacent versus overlapped hands: A pupillometric study☆

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ARTICLE INFO

Article history:
Received 3 May 2010
Received in revised form 16 November 2010
Accepted 16 November 2010
Available online 25 November 2010

Keywords:
Response preparation
Pupil diameter
Cognitive load
Reaction time

ABSTRACT

Preparatory cues facilitate performance in speeded choice tasks. It is debated, however, whether the lateralized neuro-anatomical organization of the human motor system contributes to this facilitation. To investigate this issue, we examined response preparation in a finger-cuing task using two conditions. In the hands adjacent condition, the hands were placed adjacently to each other with index and middle fingers placed on four linearly arrayed response keys. In the overlapped hand placement condition, the fingers of different hands alternated, thus dissociating hand and spatial position factors. Preparatory cues specified a subset of two fingers. Left–right cues specified the two leftmost or two rightmost fingers. Inner–outer cues specified the two inner or outer fingers. Alternate cues specified the first and third, or the second and fourth finger in the response set. In addition to reaction time and response errors, we measured the pupillary response to assess the cognitive processing load associated with response preparation. Results showed stronger pupil dilations (and also longer RTs and more errors) for the overlapped than for the adjacent hand placement condition, reflecting an overall increase in cognitive processing load. Furthermore, the negative impact of overlapping the hands on pupil dilation interacted with cue type, indicating that left–right cues (associated with two fingers on one hand) suffered most from overlapping the hands. With the hands overlapped, alternate cues (now associated with two fingers on the same hand) produced the shortest RTs. These findings demonstrate the importance of motoric factors in response preparation.

1. Introduction

About 30 years ago, Miller (1982) reported that preparing two fingers on one hand is more effective than preparing two fingers on different hands. Interpretation of this (same) hand-advantage phenomenon has sparked much debate. Miller (1982) attributed the hand-advantage to characteristics of the motor system, arguing that it is consistent with the lateralized control of hand and finger movements in the cerebral cortex. Reeve and Proctor (1984, 1985), however, questioned Miller's motoric interpretation, contending that the hand-advantage is an artifact of nonmotoric decision processes involved in translating between stimuli and responses. Recently, Adam et al. (2003, 2005) combined these notions into a coherent conceptual framework, the Grouping Model, asserting that the hand-advantage is due to a combination of attentional, perceptual, and motoric factors.

In this study, we attempted to provide new, independent evidence in support of or against the Grouping Model by examining the pupillary response as an index of cognitive processing load in response preparation. Our key manipulation was that of hand placement (adjacent vs. overlapped), which dissociates hand and spatial position factors that are confounded with the hands adjacent (Reeve and Proctor, 1984). The pupillary response supplements the traditional performance measures of reaction time (RT) and response accuracy (error rate) by providing a reliable, on-line psychophysiological measure of processing load during many cognitive tasks (for a review, see Beatty and Lucero-Wagoner, 2000), including response preparation (Moresi et al., 2008a,b). Before explicating the main theoretical frameworks, we briefly introduce the methodology of the finger-cuing paradigm and its key findings.

1.1. The finger-cuing paradigm

In the finger-cuing task developed by Miller (1982), a visual cue appears before the onset of the target stimulus. The cue indicates a subset of possible stimulus–response locations, and thus allows the advance preparation of a subset of two out of four possible finger (key press) responses. Typically, the hands are placed adjacently, with the

☆ Thanks are extended to Judith Helmink and Bart Ament for their assistance with data collection and analyses.
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doi:10.1016/j.ijpsycho.2010.11.005

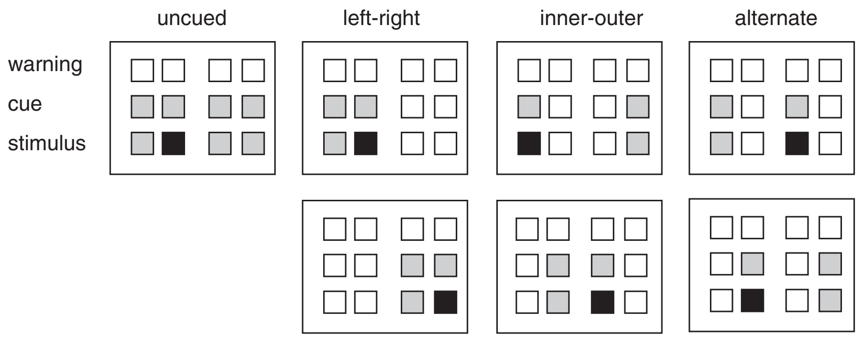

Fig. 1. A schematic representation of the finger-cuing task. Cue and target stimuli are presented in an overlaid arrangement and not in separate rows.

index and middle fingers of both hands resting on a linear array of four keys. In the present study, the visual display consisted of a horizontal row of four white boxes centered on a computer monitor. A trial started with the presentation of these four white boxes. After 1 s, the cue signal was presented by coloring two boxes grey, which allowed the selective preparation of two finger responses indicated by the cue. Then, after a delay of 2 s, the target stimulus was presented by coloring one of the two grey boxes black, which signaled the required finger response. The 2 s interval between onset of the cue signal and onset of the target signal is called the preparation interval, as it reflects the available amount of time to prepare the two finger responses indicated by the cue before the target appears. Note that whereas the present study used only one preparation interval of 2 s (to allow sufficient time for the pupil to dilate), many previous studies used a range of preparation intervals (e.g., 0, 375, 750, 1500, and 3000 ms: (Reeve and Proctor, 1984) to study the time course of response preparation.

Four cue or preparation conditions are distinguished (see Fig. 1). In the left-right cue condition, the cue indicates the two locations assigned to either the left hand (the two leftmost locations) or right hand (the two rightmost locations). In the inner–outer cue condition, the cue specifies the two locations assigned to either the index fingers (the two inner locations) or middle fingers (the two outer locations). In the alternate cue condition, the cue indicates locations assigned to the index finger of one hand and the middle finger of the other hand (the two pairs of alternate locations). These three preparation conditions are called the “cued” conditions. Also, an “uncued” control condition is included, which does not provide advance information about the upcoming response (all four boxes turn grey). In other words, the uncued condition leaves the basic four-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 two-choice tasks are substantially shorter than RTs in four-choice tasks (Hick, 1952; Hyman, 1953), cue effectiveness is inferred from a significant RT advantage or benefit for the two-choice “cued” conditions (i.e., left–right, inner–outer, and alternate) over the four-choice “uncued” condition.

The key, and often replicated, finding from the finger-cuing paradigm is a pattern of differential cuing benefits: RTs are the shortest for the left–right cue, longest for the alternate cue, and intermediate for the inner–outer cue, reflecting an ordering in terms of preparation difficulty (Proctor and Reeve, 1986, 1988; Reeve and Proctor, 1984, 1990). This pattern of differential cuing benefits is primarily present with short preparation intervals (i.e., intervals of less than about 3 s). When the preparation interval is 3 s or more, the three cued conditions often show comparable RTs and thus similar RT benefits compared to the uncued condition. This finding indicates that response preparation is a gradual process that develops over time, with left–right cues prompting a more efficient and faster response preparation process than inner–outer and alternate cues.

1.2. Salient-features coding principle

Proctor and Reeve (1986, 1988); (Reeve et al., 1992) interpreted the pattern of differential cuing benefits in terms of the salient-features coding principle. This principle assumes that stimulus and response sets are coded in terms of the salient features of each, with response selection occurring most rapidly when the salient features of the respective sets correspond. With spatial location stimuli, spatial coding predominates, with the left–right spatial distinction being the most salient feature.[1] Hence, there is an advantage for left–right cues over inner–outer and alternate cues.

Reeve and Proctor (1984) obtained critical evidence for their spatial coding account by investigating the fate of the left–right advantage with an overlapped placement of hands (i.e., the index and middle fingers of both hands alternate on the response keys in the order right index, left middle, right middle, and left index). This overlapped hand placement (see Fig. 2) dissociates hand and spatial position factors that are confounded with the usual adjacent hand placement.

Comparing finger-cuing effects with the adjacent and overlapped hand placements, Reeve and Proctor (1984, Experiment 3) found that the advantage for left–right cues is preserved with the hands overlapped, suggesting that the advantage reported by Miller (1982) really is an advantage for the two left-most and two right-most stimulus–response locations, not for fingers on left or right hands. According to Reeve and Proctor (1984, 1985, 1990) this finding implicates the stimulus–response translation stage as the locus of Miller's “hand-advantage”, which in Reeve and Proctor's view actually is a “left–right” advantage.

1.3. Grouping model

Adam and co-workers (Adam et al., 2003, 2005; Adam and Van Veggel, 1992) observed that Reeve and Proctor's result with the hand-placement manipulation might be restricted to two procedural factors: the task instructions for participants regarding the possibilities for and benefits of preparation, and the presentation mode of the preparation intervals. In particular, Reeve and Proctor (1984, Exp.1, Exp.3) did not explicitly instruct their participants to use the information provided by the cues and prepare the two indicated finger responses, nor did they group the different preparation intervals together in separate blocks of trials. According to Adam and Van Veggel (1992), both procedures might have favored the more natural, easy to prepare left–right cues, especially at short preparation

[1] Reeve and Proctor (1990) did not provide an independent, operational definition of saliency. Interpreting the observed pattern of differential cuing benefits, they simply note that “the most salient feature for linear arrays is location relative to center” (p. 178). This seems post-hoc and circular; for a discussion of this circularity problem see Adam et al. (2003) and Proctor et al. (1992).