Acta Psychologica 139 (2012) 309–313

Contents lists available at SciVerse ScienceDirect

Acta Psychologica

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

Working memory load but not multitasking eliminates the prepared reflex: Further evidence from the adapted flanker paradigm ☆

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ARTICLE INFO

Article history:
Received 16 October 2011
Received in revised form 8 December 2011
Accepted 19 December 2011
Available online 12 January 2012

PsycINFO codes:
2340
2343
2346

Keywords:
Working memory
Prepared reflex
Instructions
Flanker-compatibility

ABSTRACT

The prepared reflex (PR) metaphor (Exner, 1879; Woodworth, 1938) suggests that stimulus–response (S–R) instructions held in working memory (WM) can lead to autonomous response activation without any practice. Cohen-Kdoshay and Meiran (2007) showed flanker compatibility effects immediately following the instructions (First Trials Flanker Compatibility Effect, FTFCE) and also showed that FTFCE was eliminated when participants had to hold an additional novel task rule in mind. They attributed the elimination of the FTFCE to WM load, but did not rule out multitasking and associated increased control demands as a possible alternative explanation. In the present experiment, the authors compared a no-load condition, a load condition involving a secondary task that was changed in every block (thus requiring WM) and a multi-tasking condition involving a secondary that remained the same throughout the experiment. The results show FTFCE without load and in the multi-tasking condition but no FTFCE in the WM load condition, establishing the critical involvement of WM storage capacity in the FTFCE.

1. Introduction

To explain how stimulus–response (S–R) instructions lead to action, several authors have suggested a hypothetical mechanism called "the prepared reflex" (PR). This putative mechanism describes how stimuli can trigger the corresponding response autonomously even without any practice, and has the following characteristics: First, a mental representation of the task's S–R mapping is created following the instructions. Second, the preparation and holding of this representation demands intention and cognitive effort, and it operates within some form of working memory (WM). Third, this representation, once formed, can lead to autonomous processing (e.g., Exner, 1879; Woodworth, 1938; see also Hommel, 2000; Logan, 1978).

Recently, we provided strong evidence that supports the PR metaphor by using a modified flanker paradigm (Eriksen & Eriksen, 1974) and by analyzing the flanker compatibility effect (FCE) in the first trials immediately following the S–R instructions. In this paradigm, participants responded to a target stimulus presented at fixation. Importantly, this target stimulus was flanked by stimuli that were physically different from the target but were either mapped to the same response as the target according to the instructions (compatible) or mapped to the alternative response (incompatible). In our previous studies, we showed that responses to the target were considerably slower when the flankers were incompatible than when they were compatible. This FCE was found in the first trials (in which there was no target repetition) immediately following the S–R instructions, and we labeled it "First Trials FCE" or FTFCE, for short. We argued that the FTFCE is evidence for instruction-based autonomous response activation (Cohen-Kdoshay & Meiran, 2007). We also demonstrated the FTFCE for the **very first trial** following the instructions (Cohen-Kdoshay & Meiran, 2009) thus ruling out the possibility that the flanker compatibility effect is due to newly formed episodic memories.

The present work focuses on the role of WM in holding the representations that give rise to the FTFCE. Cohen-Kdoshay and Meiran (2007, Experiment 4) have already started to address this issue. They reported that the FTFCE was eliminated under conditions of WM load, thus demonstrating its dependence on this limited capacity buffering system. In their experiment, participants performed the flanker task while being prepared to execute a secondary go–nogo task that involved decision about numbers such as "is the number presented divisible by 3?" The secondary task's instructions changed in every block and a trial involving this task appeared once in every mini-block that included, aside from this numeric decision trial, 6 flanker task trials. The positioning of secondary task trial within the mini-block of 6 flanker trials was randomly chosen. We reasoned

☆ This research was supported by a research grant from the Israel Science Foundation to the first author. We wish to thank Yoav Kessler for very helpful comments.

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doi:10.1016/j.actpsy.2011.12.008

that by including an additional task we loaded WM and made this buffering system unavailable to hold the representations that give rise to the FTFCE. The reason for loading WM with a rule rather than with some verbal content as often done was to ensure that we load the relevant WM compartment (e.g., see Kessler & Meiran, 2010), especially given Oberauer's (2009) theory suggesting a distinction between declarative and procedural WM.

Although Cohen-Kdoshay and Meiran's (2007) results provide support for the dependence of the PR on WM, an important alternative explanation remains possible. Specifically, by including a secondary task we did not only increase the demand for information buffering but also turned the situation into one involving multi-tasking. According to this alternative account, this led to an increased demand for supervisory resources that are needed for multi-tasking coordination such as the decision which one of two tasks to execute at the given moment. Such increased control demands may lead to the elimination of FTFCE due to sharper focusing on the target (Botvinick, Braver, Barch, Carter, & Cohen, 2001) or a shift to serial processing (Logan & Gordon, 2001; Luria & Meiran, 2005; Meyer & Kieras, 1997). Consequently, the results of the fourth experiment in Cohen-Kdoshay and Meiran's study are equally well explained in terms of loading the buffer required to hold the representation of the S–R instructions (henceforth, “buffering”) and by the increased control demands (henceforth, “multi-tasking”).

The present study was conducted to decide between the two alternative explanations. In the experiment, we used three groups: The “flanker group” served for replication of the FTFCE. The other two groups also performed the flanker task while being prepared to execute a secondary task, like in Experiment 4 in Cohen-Kdoshay and Meiran (2007). In the “Varied Secondary Task”, a new secondary task was introduced on each block. This group was used to replicate the elimination of the FTFCE and had the same conditions as the WM group in Cohen-Kdoshay and Meiran's experiment. In the “Constant Secondary Task” group, the secondary task remained the same throughout the experiment including the practice phase. We reasoned that because the secondary task remained the same, the information needed to execute it would be placed in long-term memory (LTM) or as activated LTM (e.g., Cowan, 1988; Oberauer, 2001). Note that according to Oberauer (2001), activated representations in LTM are highly accessible and give rise to a sense of familiarity but cannot support performance that requires taking changing context into account. Taking the changing context into account requires representations that are bound to the context in what Oberauer (2002, 2009, see also Cowan, 1988) call “the region of direct access”, which is akin to the term WM as used in other theories.

Following this logic, both the Varied Secondary Task and the Constant Secondary Task group experienced multi-tasking, but only in the Varied Secondary Task group, this multi-tasking also necessitated maintaining the secondary task's information in the region of direct access (or WM proper). The Constant Secondary Task group experienced the secondary task during the practice phase and because the task remained the same, it could be represented as context-independent activated LTM. We therefore reasoned that, if multi-tasking is responsible for the elimination of the FTFCE, it would eliminate in the Varied Secondary Task group and the Constant Secondary Task group. If however, the exhaustion of WM buffering capacity is responsible for the elimination of the FTFCE, this effect would eliminate only in the Varied Secondary task group.

2. Experiment

2.1. Methods

2.1.1. Participants

Thirty-six Ben-Gurion University of the Negev freshmen, took part in the experiment in exchange for a course credit, and were randomly assigned to 3 experimental groups. All of the participants reported having normal or corrected-to-normal vision and being unaware of the goal of the experiment, as indicated by a post-experimental questionnaire.

2.1.2. Apparatus, stimuli and procedure

The stimuli were presented on a 17" color monitor controlled by a Pentium 4. The software for the experiment was programmed in E-Prime (Schneider, Eschman, & Zuccolotto, 2002a, 2002b). All the three groups did the flanker task and two groups also executed a secondary task as will be explained later.

2.1.2.1. The flanker task. The procedure for the flanker task was the same as that used by Cohen-Kdoshay and Meiran (2007, Experiment 4). In detail, the display of target and flankers (each 1.1 cm × 0.9 cm) was presented within a frame. The target was always flanked by two identical noise elements that were always physically different from the target, and the distance between the target and noise elements was 1.0°. The general instructions included a general description of the task (i.e., “In each trial, you will be presented with three stimuli. You need to respond only to the stimulus in the center and ignore all other stimuli”), followed by an example of possible categorization that was not used in the experimental blocks (i.e., two types of letters mapped to the right and left key, respectively) and a picture of a keyboard indicating the mapping (with no specific exemplars). These slides were used only in the practice block in order to present the participants with the general procedure. The last slide of the instructions indicated that “In the next step you will start. Prepare yourself. Press the space bar when ready”. During the instructions, the participants were asked to avoid simulating any button presses and the experimenter carefully watched them during this phase.

The unique aspect about the modified flanker paradigm is that each experimental block was associated with a new stimulus set and new S–R instructions. This enabled us to have a sufficiently large number of first trials that immediately followed the S–R instructions by accumulating them across the different S–R instructions. Each instruction set applied to a set of 12 stimuli, half mapped to one response and half to the other response. Half of the stimuli were used as targets and the other half were used as flankers, meaning that stimuli that served as flankers never served as targets in order to ensure that their influence was entirely based on instructions. Each experimental block was divided from the experimenter's perspective into 10 mini-blocks of 6 controlled trials. Within each such mini-block, there were three compatible trials and three incompatible trials. The compatible trials involved flankers that were visually different from the target, but were mapped to the same response via the instructions. This feature additionally ensured that the effect would not result from presenting flankers that were physically identical to the targets.

2.1.2.2. Secondary task. The secondary task used to load WM was a go/no-go task in response to numbers in which the response was always to press the spacebar with both thumbs (e.g., “press the space bar only when you see a number that is divisible by 4”). One go/no-go WM trial was given in a randomly chosen position within each mini-block. This trial consisted of a fixation point, presented for 500 ms, followed by a target number which remained visible until the participant responded or until 3 s had elapsed. We changed the font used to display the numbers and the number words in every block. The *Varied Secondary task* group was introduced with a **new** set of instructions in each experimental block. After each block, we asked the participants to recall the secondary task instructions, thus making sure that this information was held in WM during the block. The *Constant Secondary Task* group was introduced with the **same** set of instructions in the entire experiment including the practice phase. In this group, we used