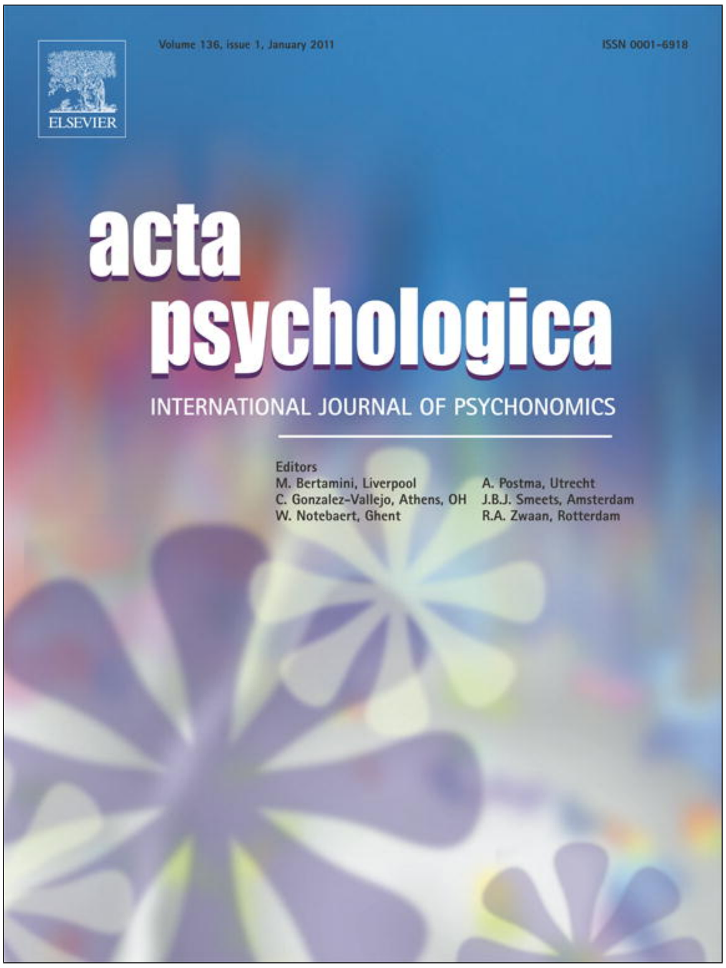
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Working memory load but not multitasking eliminates the prepared reflex: Further evidence from the adapted flanker paradigm ☆

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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

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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 two different secondary tasks that were counterbalanced across participants. In order to be able to use the same stimuli between groups, with the same proportion in each category, the rules for this group were "odd" and "even" (see Fig. 1 for the stimuli and the procedure).

2.1.3. Procedure

Each participant completed six blocks of 60 trials, each. Each block began with the mapping instructions, followed by a list of the stimuli belonging to each of the two response categories, followed by the "get ready" slide, followed by the task itself without any practice. The

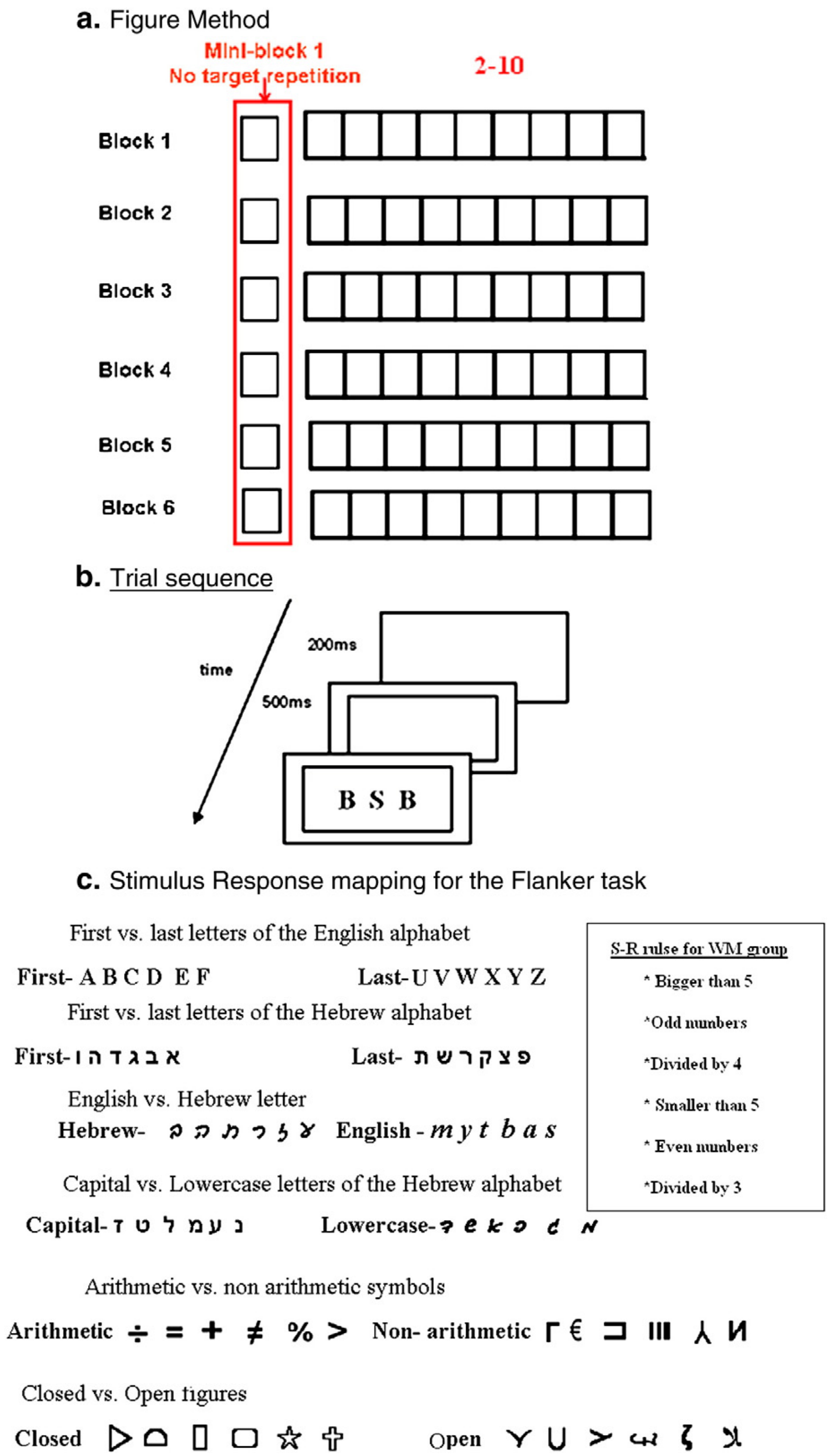

Fig. 1. (a) We presented 6 experimental blocks, each involving a unique stimulus set and S–R instructions. Each block was divided into 15 mini blocks. Each mini block included 6 flanker trials with no target repetition (for the Flanker group) and one trial of the secondary task (for the others groups). We focused on the first mini-block of the six blocks (36 trials, in total). (b) The trial sequence: Each trial began with an inter-trial interval of 200 ms, followed by a black frame presented in the center of the screen, followed by the display that remained visible until the response was given. (c) Stimulus–response mappings used in the experiments.

order in which the sets of instructions were given was counterbalanced by a Latin square.

Participants were tested individually in one session, lasting approximately 30 min. Testing took place in a dimly lit room, and the participants were seated about 50 cm from the computer monitor. In the beginning of the experiment, the participants executed one block of the flanker task to familiarize themselves with the general task structure in order to be sure that in the subsequent blocks the location of the flankers and the target is clear. This block was based on a set of instructions and stimuli that were **not** used in the subsequent blocks and was considered as practice and was not analyzed. It was included thirty *incompatible* trials to ensure that the participants adopt the strategy of focusing on the target (because responding to flankers would have generated an error). Moreover, if the participant committed an error during these practice trials, an error message appeared in red letters, accompanied with a 350 Hz beep lasting for 500 ms. After this phase, the Varied secondary task and constant secondary task groups executed another 30 trials of practice with the secondary task, this task was presented once in a randomly chosen position within each mini-block that included 6 flanker trials. The flanker trial sequence was as follows. At the beginning of each trial, a black frame was presented on a white background. After 500 ms, the target and flankers were presented within a frame. The display remained visible until the participant responded. Flanker task's responses were made by pressing the “z” (left) and “/” (right) keys on a standard computer keyboard, with the left and right index fingers, respectively. The mapping of the response category to the response key was counterbalanced across participants. We used an inter-trial interval of 200 ms.

2.2. Results

Mean RTs were calculated as a function of Group and Compatibility only for the first mini blocks of trials immediately following their S–R instructions. Response latencies quicker than 100 ms or exceeding 3000 ms were discarded as deviant (1.8%) and were not analyzed for RT. We adopted an α=.05 in all the analyses. When analyzing results from the Varied Secondary Task group or the Constant Secondary Task group, we did not analyze the flanker task trials that immediately followed these tasks because these trials represent task switching. We employed the pooled error term across groups as recommended by Kirk (1968, p. 267) when used planned contrasts for the FTFCE. We adopted this approach to maximize the statistical power, as needed when seeking conditions in which the FTFCE eliminates.

2.2.1. Manipulation check

We assumed that adding a secondary task would influence overall RT (Fig. 2) and the proportion of errors (PE, see Table 1). Specifically we expected that the responses in the Flanker Group would be either faster, less error prone or both as compared to the other groups. Such a result would show that the WM load manipulation was sufficiently potent to influence performance. This prediction was supported for RT but not for errors. Specifically, responses in the Varied Secondary Task group were significantly slower than in the Flanker group, F (1, 33) = 6.64, η^2 = .17. However, the average PE did not differ significantly between the groups. We had similar predictions for the Constant Secondary Task group who also produced slower responses than the Flanker Group (715 vs. 635 ms), but this difference did not reach significance, F (1, 33) = 2.05, p<.161, η^2 = .06 Nonetheless, the planned contrast indicated a significantly higher error rate in the Constant Secondary Task group than in the Flanker group, F (1, 33) = 5.17, η^2 = .14. A comparison between the Constant and Varied Secondary Task groups indicated that they did not differ significantly from one another in RT, F (1, 33) = 1.33, p = 0.26, η^2 = .04 but differed significantly in PE. F (1, 33) = 6.61, η^2 = .17. Although we do not provide an explanation for this last finding, we do not see how it could have compromised our main conclusions. Moreover, the finding rules out the possibility that the load in the Constant Secondary Task group was insufficiently high and that this is why it did not eliminate the FTFCE (see below).

As mentioned before, one trial of the secondary task was given in each mini block of the flanker task. All the participants correctly recalled the instructions for the secondary task, and did so in all the blocks. In terms of performance, only one participant made errors in the first mini-blocks, which allows us to conclude that the information for the secondary task was held in WM while performing this critical mini-block for the remaining participants.

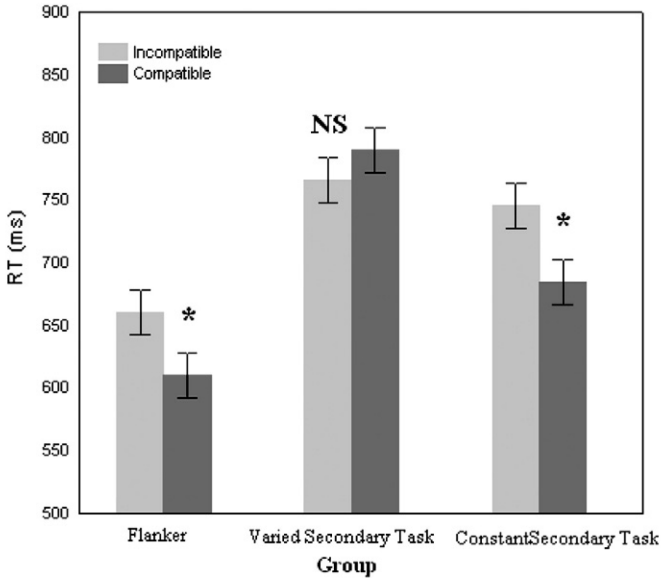

Fig. 2. Mean RT (ms) According to Compatibility and Group for the First Mini-Block of Trials Following the S–R Instructions. (Bars indicate the standard errors for the flanker compatibility effect within each group). NS = non significant.

2.2.2. Checking the core prediction

We turn now to our main hypothesis. Significant main effects were found for Compatibility, F (1, 33) = 4.98, η^2 = .13, indicating a FTFCE, and Group F (2, 33) = 3.32, η^2 = .17. The interaction between Compatibility and Group was also significant, F (2, 33) = 4.16, η^2 = .20, reflecting that the FTFCE was different between groups. The size of the FTFCE was 50, −24, and 61 ms in the Flanker, Varied and Constant Secondary Task groups, respectively. We conducted three focused contrasts in order to examine the FTFCE (see Fig. 2), This contrast was significant only for the Flanker group and the Constant Secondary Task groups, F (1, 33) = 4.95, η^2 = .13, and , F (1, 33) = 7.26, η^2 = .18, respectively, but was non-significant in the Varied Secondary Task group, F (1, 33) = 1.1, p<0.3, in which the numeric trend was even reversed.

Table 1
Proportion of errors as a function of compatibility and group.

	Compatible	Incompatible
Flanker group	0.01	0.01
Varied secondary task	0.01	0.01
Constant secondary task	0.03	0.04

3. Discussion

The goal of this study was to establish the critical role of the WM in holding the PR-related representations. Our experimental approach was based on the logic of loading the limited capacity WM and on Oberauer's (2001, 2002, 2009) conceptualization of limited capacity WM ("region of direct access"). Oberauer views it as a system for holding novel bindings including novel bindings with context.

Based on this approach, we devised conditions in which participants were ready to execute a secondary go/no-go task that was required in the minority of the trials and contrasted two conditions. In the Constant Secondary Task condition, the secondary task's information remained unchanged throughout the experiment including the practice phase, which made it unnecessary to bind the secondary task's information to the changing block context, thus not requiring the region-of-direct-access. In the Varied Secondary Task condition, the load task changed in every block, making it necessary to hold this task's information in the region-of-direct-access. Since there was a secondary task in both cases, they involved multitasking.

The results are straightforward. We found FTFCE in the No Load condition and a non-significant (and slightly reversed) FTFCE in the Varied Secondary Task group, thus replicating Cohen-Kdoshay and Meiran's (2007) results. The novel finding was the significant FTFCE in the Constant Secondary Task group which was numerically roughly equivalent to that in the no-load condition. This finding shows that multitasking requirements do not eliminate the FTFCE.

The conclusion that limited capacity WM (region of direct access) is critical for the FTFCE accords with Wilhelm and Oberauer (2006) who, employing an individual differences design, showed a that the correlation between WM and RT was much higher when RT was measured in tasks employing arbitrary S–R mapping (requiring WM) than in tasks employing compatible mapping (that can rely on LTM). It may also explain the lack of PR-related phenomena in Waszak, Wenke, and Brass (2008) study. Specifically, Waszak et al. used a task switching design characterized by holding in mind 8 S–R rules in readiness for execution, among which 4 rules were in a status resembling the 2 rules in our paradigm when immediately following the instructions. We would therefore argue that in Waszak et al.'s study, the capacity of the region-of-direct-access was already exhausted, thus preventing reflex-like behavior.

Duncan et al. (2008) examined the influence of various types of WM load on the phenomenon of goal neglect in which participants are asked to report characters presented on the right or left of fixation and fail to shift the reported side in response to a cue. These authors found that increasing search load or control demands via task switching requirements did change goal neglect rates. However, goal neglect was increased by increasing the complexity of the novel task instructions, a state that presumably loads the region of direct access.

Before concluding we note that participants remained accurate and were only relatively little slowed even in conditions in which the FTFCE was eliminated. This implies that highly efficient performance, seen also in reflex-like performance (FTFCE) depends on low load. When load is high, performance is still possible but it becomes slightly slower and less automatic. Possibly, when the capacity of the region-of-direct-access is exhausted, participants can still split the information load between this system and activated LTM in a manner that makes it still possible to execute the task at hand albeit slightly less efficiently.

We also wish to acknowledge the fact that that the load tasks that we used involved stimulus (or stimulus category)-to-response rules. We concluded that it is the storage capacity of the region-of-direct-access that is responsible for the FTFCE. However, Oberauer (2009) argued that WM comprises of a declarative part and a procedural part. Actually, our choice of loading task was based on this theory. Thus, our results allow us to conclude regarding the storage capacity limitations of *procedural* WM. We cannot be completely sure whether our conclusions extend to the *declarative* WM.

In conclusion, the present results provide evidence that novel task instructions held in the limited capacity buffering system, the region of direct access (Oberauer, 2009) behave in a reflex-like manner in accordance with the prepared reflex metaphor, suggested many years ago by Exner (1879) and Woodworth (1938).

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