This is the accepted version of the manuscript, which has been published as:

Luna, F. G., Telga, M., Vadillo, M. A., & Lupiáñez, J. (2020). Concurrent working memory load may increase or reduce cognitive interference depending on the attentional set. *Journal of Experimental Psychology: Human Perception and Performance*, *46*(7), 667–680. https://doi.org/10.1037/xhp0000740

Concurrent working memory load may increase or reduce cognitive interference depending on the attentional set

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This study was supported by the Ministerio de Economía y Competitividad, España, with research project to JL (PSI2017-84926-P), and by the Secretaría de Ciencia y Tecnología from the Universidad Nacional de Córdoba, Argentina (Proyecto Estimular to FGL). In addition, FGL received PhD scholarship support from the Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Argentina, and a scholarship mobility by the Asociación Universitaria Iberoamericana de Posgrado (AUIP) in cooperation with the

Consejería de Economía y Conocimiento de la Junta de Andalucía, España. MT received a pre-doctoral FPU fellowship (FPU14/07106) from the Ministerio de Educación, Cultura y Deporte, España. MAV was supported by grants 2016-T1/SOC-1395 from Comunidad de Madrid (Programa de Atracción de Talento Investigador) and PSI2017-85159-P from Agencia Estatal de Investigación, Ministerio de Economía y Competitividad, España.

Preliminary results of this work has been presented in the First Joint Congress of the SEPEX, SEPNECA and AIP experimental, developed from 3rd to 6th of July 2018 in Madrid, Spain, and in the 12th Scientific Meeting of Attention (RECA), developed from 3rd to 5th of October 2019 in Almería, Spain.

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The data set of this study is publicly available in the Open Science Framework, at: https://osf.io/fnrct/.

Word count: 9174.

Abstract

Perceptual grouping leads to interference when target and distractors are integrated within the same percept. Cognitive control allows breaking this automatic tendency by focusing selectively on target information. Thus, interference can be modulated either by goal-directed mechanisms or by physical features of stimuli that help to segregate the target from distractors. In three experiments, participants had to respond to the left-right direction of a central arrow, flanked by two arrows on each side. Sometimes, instructions requested to also stay vigilant for detecting an infrequent vertical/horizontal displacement of the target, thus loading working memory. While it has been usually shown that concurrent working memory load hinders target selection, the present research provides evidence that interference may either increase or decrease depending on whether dual tasking draws attention to the grouping (horizontal displacement) or to an orthogonal dimension (vertical displacement), revealing counter-intuitive benefits of working memory load.

Keywords

Working Memory, Cognitive Control, Attentional Set, Interference Effect, Dual Task Performance.

Public Significance Statement

Cognitive control mechanisms help us to focus our attention only on the relevant stimuli of the environment while ignoring irrelevant information, to achieve the goals demanded by the task performed at a specific moment. Although cognitive control is usually impaired by the simultaneous performance of a secondary task, some studies have found the opposite result or have failed to find any effect of secondary task at all. In the present study, we observed that if the secondary task promotes the grouping of relevant and irrelevant stimuli, then cognitive control is indeed hindered. However, if the secondary task incidentally helps to segregate the relevant stimuli from the irrelevant ones, then cognitive control improves. Therefore, we demonstrate that the difficulty posed by having to perform two tasks simultaneously can be considerably reduced, depending in particular on the set of instructions kept in mind.

Conflict situations require adapting our behavior to achieve our goals (Mansouri, Tanaka, & Buckley, 2009). These adjustments are implemented by a set of processes known as cognitive control, which are necessary to develop, maintain, and execute plans for actions (Badre, 2008; Egner, 2008). To assess cognitive control functioning, a widely used behavioral paradigm is the Eriksen flanker task. In this paradigm, irrelevant stimuli (i.e., distractors) interfere with the selection of a specific target, as revealed by slower and less accurate responses when the distractors are incongruent with the target, than when they are congruent (Eriksen & Eriksen, 1974). Importantly, there is a large body of evidence supporting the idea that performing two or more tasks simultaneously hinders cognitive control (Caird, Willness, Steel, & Scialfa, 2008; Dressel & Atchley, 2008; Jansen, van Egmond, & de Ridder, 2016; Salvucci & Taatgen, 2008; Wickens, 2008). In particular, increasing the number of instructions kept in mind to perform several tasks at the same time seems to overload the working memory capacity, reducing the ability to select the target from distractors stimuli and, consequently, increasing interference.

Currently, one of the most widely accepted theoretical frameworks to account for the detrimental effects of dual tasking on cognitive control is the load theory of selective attention, which states that concurrent working memory load reduces the available attentional resources and, consequently, increases distractors’ interference (Gil-Gómez de Liaño, Stablum, & Umiltà, 2016; Lavie, Hirst, de Fockert, & Viding, 2004). However, several studies have reported conflicting results, revealing that dual tasking can sometimes benefit rather than hinder target selection (Gil-Gómez de Liaño, Umiltà, Stablum, Tebaldi, & Cantagallo, 2010; Kim, Kim, & Chun, 2005; Park, Kim, & Chun, 2007). In addition, previous studies have demonstrated that the specific mindset maintained in working memory can be critical to reduce the distractors’ interference (Goldfarb, Aisenberg, & Henik, 2011;

Liefooghe, Wenke, & De Houwer, 2012; Wenke, De Houwer, De Winne, & Liefooghe, 2014).

It is well known that cognitive control can be modulated either by salient features of stimuli or by goal-directed mechanisms (Awh, Belopolsky, & Theeuwes, 2012; Connor, Egeth, & Yantis, 2004; Notebaert, Gevers, Verbruggen, & Liefooghe, 2006; Shomstein, 2012; Theeuwes, 2010). Thus, on the one hand, the difficulties to segregate the target from distractors may be the natural consequence of an automatic tendency of the perceptual system to group similar stimuli into a single set (White, Ratcliff, & Starns, 2011), so that attention is spontaneously spread through the entire group of stimuli (Egly, Driver, & Rafal, 1994; Marotta, Lupiáñez, Martella, & Casagrande, 2012). Consistent with this, the physical features of stimuli may modulate the allocation of the attentional focus. For instance, presenting the target and the distractors in separate background objects (e.g., one box for each stimuli) can benefit the selection of the target, compared to presenting all stimuli within a single background object. Seemingly, the boundaries of the background objects prevent any 'attentional spreading' over the perceptual group (Kramer & Jacobson, 1991; Luo & Proctor, 2016; Richard, Lee, & Vecera, 2008). This type of object-based modulation is observed when the physical features of the target and the background are related (e.g., a rectilinear shape over a rectangle), but not when they are unrelated (e.g., letters overwritten on a rectangle) (Richard et al., 2008; Shomstein & Yantis, 2002).

On the other hand, in tasks in which all stimuli share the same physical features, goal-directed control is necessary for target selection (Liefooghe et al., 2012; Wenke et al., 2014). Jonides and Gleitman (1972) observed that selecting the character 'O' in a set of stimuli with letters as distractors is easier if participants are instructed to interpret the target as a digit (i.e., the number 'zero') than as a stimulus of the distractors' category (i.e., the letter 'o'). Recently, Avital-Cohen and Tsal (2016) found a similar effect in a flanker task that included ambiguous stimuli, e.g., the letter ‘S’ as the target and a set of numbers ‘5’ as distractors. Interference decreased when instructions anticipated the distractors to be digits, and increased when the distractors were expected as letters. Therefore, instructions can induce a specific mindset that affects grouping and thus distractors interference.

In the same vein, it has been shown that cognitive control can be enhanced if the mindset is manipulated to avoid deploying attention over a task-irrelevant stimuli dimension. In the study conducted by Goldfarb et al. (2011), participants completed the typical Stroop color-word task. Importantly, before performing the task, the mindset could be influenced or not by a particular social priming manipulation: participants were asked to think about the difficulties that a person with dyslexia might have to perform several daily live activities. This social priming was expected to reduce participants’ attention to word reading in the Stroop task (i.e., the task-irrelevant dimension), thus attention being instead deployed only to the color of the word (i.e., the task-relevant dimension). In line with the authors’ expectations, cognitive control improved after the mindset modulation, thus reducing Stroop interference (Goldfarb et al., 2011).

Consistently with this, Luna, Marino, Roca, and Lupiáñez (2018) also observed that participants’ mindset may substantially impact cognitive control performance. In particular, Luna et al. (2018) incidentally observed that having in mind the intention to detect an infrequent displacement of the target while performing a selective attention task can either benefit or impair target selection. The original goal of the study was to analyze simultaneously the functioning of several attentional processes (i.e., phasic alertness, orienting, cognitive control, and both the executive and arousal components of vigilance). Participants had to complete a flanker task, attempting to discriminate the direction of a central arrow (target), flanked on each side by two distracting arrows pointing in either the same or opposite direction. The embedded executive vigilance task consisted in detecting a large displacement of the target from its central position, which occurred in a small proportion of trials (i.e., 25%). Importantly, in two experiments, the authors compared two different versions of the vigilance task: whereas one group should detect a horizontal displacement of the target (either leftwards or rightwards), the other one had to detect a vertical displacement (either upwards or downwards).

In the two experiments conducted by Luna et al. (2018), faster reaction times (RT) and fewer errors were observed for the vertical than for the horizontal displacement condition. Furthermore, although no specific prediction was anticipated, interference was substantially reduced in the vertical displacement condition compared to the horizontal one, for both RT and errors. It is important to highlight that cognitive control was measured on exactly the same type of trials (i.e., without the large target displacement) in the two task versions, the only difference between them being the attentional set induced by the vigilance task for detecting either the vertical or the horizontal displaced targets in the remaining non-analyzed trials (Luna et al., 2018).

The present study

The current research was motivated by these recent findings showing opposite effects of distractors' interference in dual tasking conditions. With the aim to clarify under which specific circumstances concurrent working memory load either improves or hinders cognitive control functioning, in the present study we have examined the hypothesis that the specific attentional set maintained in working memory can have a beneficial or detrimental effect on target selection in dual tasking situations.

According to previous empirical evidence (de Fockert, 2013) and established theorizing (Lavie, 2010; Lavie et al., 2004), concurrent working memory load should lead to reduced cognitive control in all cases, thus increasing interference from distractors. However, the findings reported by Luna et al. (2018) show that, depending on the nature of the attentional set, cognitive control can be either enhanced or hindered: interference was reduced by attention being deployed to the up/down target's displacement and increased by attention being deployed to the left/right direction of the displacement.

Taking into account that the findings of Luna et al. (2018) were observed by serendipity, and noting that mixed, opposite, or not-replicable results have been observed in this field (Gil-Gómez de Liaño et al., 2016, 2010; Kim et al., 2005), the present study aimed at confirming that the nature of the attentional set can increase or reduce distractors' interference in dual tasking conditions. To this end, we conducted the following experimental series wherein working memory could be overloaded or not depending on whether participants were asked to perform two tasks simultaneously or just a single task, respectively. Importantly, in the dual tasking condition, participants could be instructed to deploy attention either over the grouping dimension of target and distractors (thus increasing distractors' interference), or to an orthogonal dimension that helped to segregate the target from distractors (thus reducing distractors' interference). Note that, whereas Experiment 1 was conducted as a control study of the serendipitous results reported previously by Luna et al. (2018), Experiments 2 and 3 were conducted following a pre-registered procedure and analysis plan that is publicly available at the Open Science Framework (OSF, http://osf.io/erqv9). Thus, the present research aimed at clarifying under which specific circumstances wherein working memory is overloaded by dual tasking, target selection can be either benefitted or hindered depending particularly on the attentional set kept in mind.

Experiment 1

The present experiment was originally designed as a control study for the modulation of distractors' interference reported by Luna et al. (2018). To this end, participants completed a behavioral task with exactly the same set of stimuli and procedure of Experiment 2 in Luna et al. (2018). However, and most importantly, here participants were instructed to perform only the flanker task, without having to detect the displaced targets or to solve the embedded arousal vigilance task (i.e., stopping a millisecond counter). We hypothesized that, if the differences observed by Luna and et al. (2018) between the vertical and the horizontal version of the task were stimulus driven, i.e., due to the occasional vertical vs. horizontal displacement of the target, then these differences should still be observed here, in spite of the displacement being irrelevant. However, if the modulation of interference was rather due to the attentional set induced by the need to pay attention to the vertical or the horizontal displacement, then no differences should be observed in this control experiment, as no attention should be devoted to the infrequent stimuli detection, or at least no intention to attend to it.

Method

Participants.

Participants (*N* = 48; 43 women) were students from University of Granada, Spain (age: *M* = 19.94, *SD* = 2.58). In this experiment, the sample size was the same as in Experiment 1 of Luna et al. (2018). All participants in the present series of experiments had normal or corrected to normal vision. In addition, in this and the following experiments, participants were recruited voluntarily, evaluated individually in a single session, signed a written informed consent, and received course credit for their participation. The studies were conducted according to the ethical standards of the 1964 Declaration of Helsinki (last update: Seoul, 2008) and were part of a larger research project approved by the University of Granada Ethical Committee (175/CEIH/2017).

Procedure and design.

Participants completed the two versions of the Attentional Networks Test for Interactions and Vigilance – executive and arousal components (ANTI-Vea) administered in Experiment 2 of Luna et al. (2018). In this and the following experiments, scripts were developed and run in E-Prime 2.0 (Psychology Software Tools, Pittsburgh, PA). The sequence and timing of stimuli, and response keys, are detailed in Luna et al. (2018).

The ANTI-Vea includes three types of trials: ANTI (a flanker task with warning signals and visual cues that may appear before the target), executive vigilance (EV, to explore the detection of infrequent events across time), and arousal vigilance (AV, to measure the sustenance of a fast reaction to stimuli without response selection). The flanker task consists in detecting the direction pointed by a central arrow (left/right), surrounded by two distracting arrows on each side. Participants were randomly assigned to one of two groups, which performed identical tasks except for the direction of the target displacement from its central position in the EV trials. In the horizontal version the target was displaced either leftwards/rightwards, whereas in the vertical version it was displaced either upwards/downwards.

Importantly, in contrast to the study of Luna et al. (2018), in the present experiment participants only had to perform the flanker task. Therefore, first participants received instructions to complete the ANTI trials, with a practice block of 32 randomized trials (16 ANTI and 16 EV) with feedback. ANTI and EV trials were presented embedded in the first practice block because in this task participants should not respond differently to the possible horizontal or vertical displacement of the target in EV trials. They only had to detect the direction the central arrow pointed to. So, if the target was displaced and participants responded correctly to the arrow’s direction, then feedback was given as a correct response.

After that, participants were told that sometimes a millisecond counter could appear (i.e., the AV trials) and the correct answer was to do nothing until it disappeared from screen. Then, a new practice block of 48 randomized trials (16 ANTI, 16 EV and 16 AV) with feedback was presented. Finally, an additional practice block of 40 randomized trials (24 ANTI, 8 EV and 8 AV) without feedback was presented. The six experimental blocks (without pause nor feedback) comprised 80 randomized trials (48 ANTI, 16 EV and 16 AV) within each block.

Data analyses.

Importantly, for the hypotheses of the current experiment, analyses were conducted including only responses to the ANTI trials. Therefore, interference was analyzed on the same type of trials in the two task versions, i.e., those wherein the target was not largely displaced from its central position.

In this and the following experiments, analyses were performed in Statistica 8.0 (StatSoft Inc.) and Matplotlib 3.0.0 (Hunter, 2007) was used to create the figures. First, data was pre-processed following the same criteria of the study conducted by Luna et al. (2018). Two participants with an extreme average reaction time (RT) and one with an extreme average percentage of errors (i.e., 2.5 SD above the group mean) were excluded from further analyses. In the RT analysis, trials with an incorrect response (3.24%) or with RT below 200 ms or above 1500 ms (0.57%) were also excluded. Then, two mixed ANOVAs, one for RT and another for errors as dependent variables, were conducted including warning signal (no tone/tone), visual cue (invalid/no cue/valid), and congruency (congruent/incongruent) as within-participants factors, and task version (horizontal/vertical) as a between-participants factor. In this and the following experiments, statistical significance was established at .05 and CIs at 95%.

Results

The main effects usually reported with the ANTI task were significant in this experiment as well (see Table 1). Thus, for warning signal, responses were faster and more precise in the tone than in the no tone condition (RT: [F (1, 43) = 142.33, p < .001, η_p^2 = .77, 95% CIs (.63, .84)]; errors: [F (1, 43) = 6.20, p = .016, η_p^2 = .13, (.00, .31)]). The main effect of visual cue demonstrated that responses were faster and more precise in the valid condition, than in the no cue and invalid ones (RT: [F (2, 86) = 86.90, p < .001, η_p^2 = .67, (.55, .74)]; errors: [F (2, 86) = 14.20, p < .001, η_p^2 = .25, (.10, .38)]). Importantly, the congruency effect showed that responses were faster and more precise in the congruent than in the incongruent condition (RT: [F (1, 43) = 312.77, p < .001, η_p^2 = .88, (.80, .91)]; errors: [F (1, 43) = 50.23, p < .001, η_p^2 = .54, (.32, .67)]). However, as predicted in the hypotheses of the present experiment, the main effect of task version was not significant, neither for RT [F (1, 43) = 0.52, p = .476, η_p^2 = .01, (.00, .14)] nor for errors [F (1, 43) = 0.03, p = .853, η_p^2 = .00, (.00, .07)]. Overall mean RT was similar for the vertical (526 ms, 95% CIs [501, 552]) and the horizontal versions (513 ms, [489, 538]), and the mean proportion of errors was similar for the vertical (2.98%, [2.11, 3.85]) and the horizontal versions (3.09%, [2.22, 3.94]).

The following interactions, usually observed with the ANTI task, were also significant: Warning signal × Visual cue (only for RT: [F (2, 86) = 25.85, p < .001, η_p^2 = .38, (.21, .50)]; errors: F < 1), Warning signal × Congruency (only for RT: [F (1, 43) = 27.41, p < .001, η_p^2 = .39, (.16, .55)]; errors: [F (1, 43) = 2.30, p = .137, η_p^2 = .05, (.00, .21)]), and Visual cue × Congruency (RT: [F (2, 86) = 20.57, p < .001, η_p^2 = .33, (.16, .44)]; errors: [F (2, 86) = 8.69, p < .001, η_p^2 = .17, (.04, .30)]). In addition, and only for errors, there was a significant interaction between Warning signal × Visual cue × Task version [F (2, 86) = 3.57, p = .032, η_p^2 = .08, (.00, .19)].

Importantly, as anticipated, the Congruency × Task version interaction was not significant, neither for RT [F (1, 43) = 0.04, p = .838, η_p^2 = .00, (.00, .08)] nor for errors [F (1, 43) = 0.99, p = .325, η_p^2 = .02, (.00, .16)]. Thus, the interference effect was similar for the vertical (RT: 55 ms, [46, 64]; errors: 2.93%, [1.74, 4.12]) and the horizontal versions (RT: 56 ms, [47, 66]; errors: 3.89%, [2.30, 5.48]).

Table 1. Mean correct RT (ms) and percentage of errors, as a function of warning signal, visual cue and congruency in each task version (horizontal/vertical).

		Horizontal				Vertical			
		Congruent		Incongruent		Congruent		Incongruent	
		M	95% CI	*M*	95% CI	*M*	95% CI	*M*	95% CI
Reaction Time									
No tone	Invalid	508	[483, 533]	566	[536, 597]	518	[493, 544]	591	[560, 622]
	No cue	530	[503, 557]	561	[535, 587]	547	[519, 575]	569	[543, 596]
	Valid	495	[466, 525]	532	[505, 560]	497	[466, 527]	540	[512, 568]
Tone	Invalid	479	[451, 508]	566	[536, 597]	493	[464, 523]	577	[546, 608]
	No cue	460	[435, 484]	524	[500, 548]	477	[452, 502]	529	[505, 554]
	Valid	442	[417, 467]	502	[478, 526]	461	[435, 486]	516	[492, 541]
Errors									
No tone	Invalid	1.99	[0.88, 3.10]	8.88	[5.81, 11.95]	2.27	[1.14, 3.41]	5.87	[2.73, 9.01]
	No cue	2.36	[1.13, 3.58]	4.17	[2.05, 6.29]	2.08	[0.83, 3.34]	3.98	[1.81, 6.14]
	Valid	1.27	[0.01, 2.53]	3.44	[1.71, 5.17]	2.27	[0.98, 3.56]	3.60	[1.83, 5.37]
Tone	Invalid	0.36	[-0.60, 1.32]	6.34	[3.42, 9.26]	1.52	[0.53, 2.50]	7.39	[4.40, 10.37]
	No cue	0.72	[0.17, 1.28]	3.62	[1.62, 5.62]	0.19	[-0.37, 0.75]	2.46	[0.42, 4.51]
	Valid	0.18	[-0.49, 0.85]	3.80	[1.89, 5.71]	0.76	[0.08, 1.44]	3.41	[1.46, 5.36]

Note: *M* = Mean; CI = Confidence Interval

To effectively determine whether the interference effect is specifically modulated by having in mind the intention to detect an infrequent horizontal/vertical displacement of the target, and not just by the perceptual appearance of displaced targets, we decided to jointly analyze the interference effect across the three experiments discussed so far (i.e., Experiments 1 and 2 of Luna et al., 2018, and the current experiment). Thus, we conducted two ANOVAs including the interference effect (either for RT or percentage of errors) as a single dependent variable, and Experiment (three levels) and Task Version (two levels, i.e., horizontal/vertical) as categorical factors. As expected, the Experiment × Task version interaction was statistically significant both for RT [F (2, 161) = 12.31, p < .001, η_p^2 = .13, (.05, .23)] and errors [F (2, 161) = 13.09, p < .001, η_p^2 = .14 (.05, .23)], which demonstrates that interference is considerably reduced in the vertical displacement condition and increased in the horizontal displacement one but only when dual tasking demands to simultaneously detect the displacement of the target (see Fig. 1).

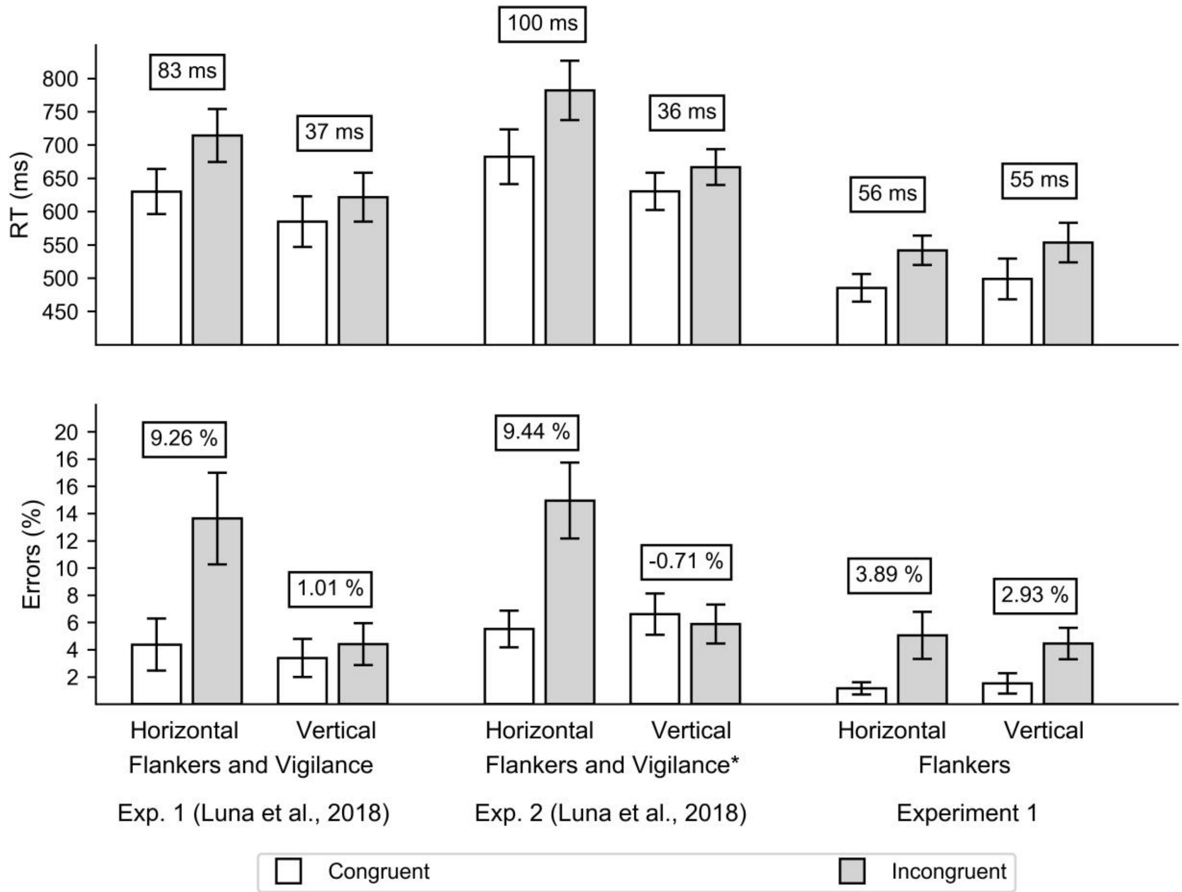

Fig. 1. Mean correct RT (superior panel) and percentage of errors (inferior panel) for congruency conditions in the flanker task, as a function of the attentional set demanded in the different experiments and task versions. The boxes over each pair of bars show the interference effect (i.e., the difference between incongruent and congruent conditions) for that attentional set. Error bars represent 95% confidence intervals. *The second experiment of Luna et al. (2018) included an embedded arousal vigilance task (i.e., stopping a down counter as fast as possible).

Experiment 2

In the present experiment, we aimed at replicating the differences observed previously in the interference effect as a function of the attentional set, this time in a single within-participants design and without the added stimuli used in the experimental tasks of Luna et al. (2018) necessary for measuring other attentional processes. To this end, here participants completed four different experimental blocks either in single or dual task conditions, with the secondary task demanding detection of either a horizontal or a vertical displacement of the target. Therefore, all the experimental conditions of Experiment 1 and the tasks administered by Luna et al. (2018) were manipulated within participants in a single experimental task. The hypotheses for the present experiment were pre-registered in OSF (https://osf.io/erqv9). In particular, when participants were asked to perform just the flanker task, we expected a similar size of interference (for both RT and errors rate) in the blocks with the horizontal and vertical displacement of the target. However, when participants were instructed to detect the displacement while performing the flanker task, we anticipated an increase in interference in the horizontal displacement stimuli set and a reduction of interference (even to a smaller size than when just performing the flanker task) in the vertical one.

Method

Participants.

Twenty (14 women) undergraduate students from the University of Granada, Spain (age: *M* = 19.15, *SD* = 2.06) participated in this experiment. Sample size was estimated a priori using G*Power 3.1.9.2 (Faul, Erdfelder, Lang, & Buchner, 2007), based on the effect size (η_p^2 = .41) of the Task version × Congruency interaction found for RT in the first experiment reported by Luna et al. (2018). We estimated that at least 14 participants would be needed to replicate the above mentioned effect with a power of $1 - \beta = .95$ and an alpha of

.05. Then, to have the same number of participants in each of the four counterbalance conditions (see the Procedure and design section below for details), and anticipating the need for replacing outliers, we decided to gather data from 20 participants.

Apparatus and stimuli.

The set of stimuli was the same in this and the following experiment. Participants sat at ~50 cm from the screen, which had a resolution in pixels (px) of 1024 wide and 768 height. Stimuli and instructions were presented in black over a grey background and responses were registered with a standard keyboard. The stimuli were the same as in the experimental tasks used in Luna et al. (2018): a black fixation cross (~7 px) and a row of five black arrows (50 px wide × 23 px high each arrow) pointing either leftward or rightward. The horizontal distance between adjacent arrows was approximately 63 px. To make more difficult the detection of the large displacement of the target (fixed to 8 px from its central position) when it was required, a random variability of ±2 px was set on the horizontal and vertical position of each arrow across the different trials.

Procedure and design.

The experimental task consisted of four different blocks of trials. In each of them, participants performed a flanker task, pressing the correct key according to the direction the central arrow pointed to (“c” for left, and “m” for right), while ignoring the flanking arrows. In half of the trials, the target and flankers pointed in the same direction (congruent condition), whereas in the other half the target pointed in the opposite direction (incongruent condition). In 20% of the trials, the target was quite displaced (i.e., 8 px) from its central position. In two of the four blocks, this positional displacement could be either leftwards or rightwards (horizontal condition), and in the other two either upwards or downwards (vertical condition).

In addition, within each displacement condition (horizontal or vertical), participants were instructed to perform different tasks from one block to another. In one of the two blocks, they had to respond to all the trials according to the direction of the target, ignoring any displacement of the central arrow (flanker task condition). In the remaining block, participants were encouraged to perform the main flanker task while staying vigilant to detect the large displacement of the target by pressing the space bar, ignoring the direction of the target in these trials (flanker and vigilance task condition).

In summary, participants had to complete four different experimental blocks: (a) all trials as a flanker task, including 20% with the horizontally displaced target; (b) all trials as a flanker task, including 20% with the vertically displaced target; (c) 80% of trials as a flanker task, while staying vigilant to detect the 20% of trials with the target horizontally displaced; and (d) 80% of trials as a flanker task, while staying vigilant to detect the 20% of trials with the target vertically displaced. Blocks could be arranged in one of four possible sequences, counterbalanced across participants according to the displacement condition (horizontal or vertical) and, within each displacement condition, the task to perform (flanker alone or flanker and vigilance).

All trials followed the exact same procedure and timing (see Fig. 2). Trials began with a blank screen with a fixation point for a random time between 400 and 1600 ms and finished with the same blank screen with the fixation point until the total trial time reached 3600 ms. This random timing for beginning and ending made participants uncertain about the beginning of the next trial. The row of five arrows could appear either above or below the fixation point, as in Luna et al. (2018), and remained on the screen for 200 ms. Participants' responses were allowed up to 2000 ms.

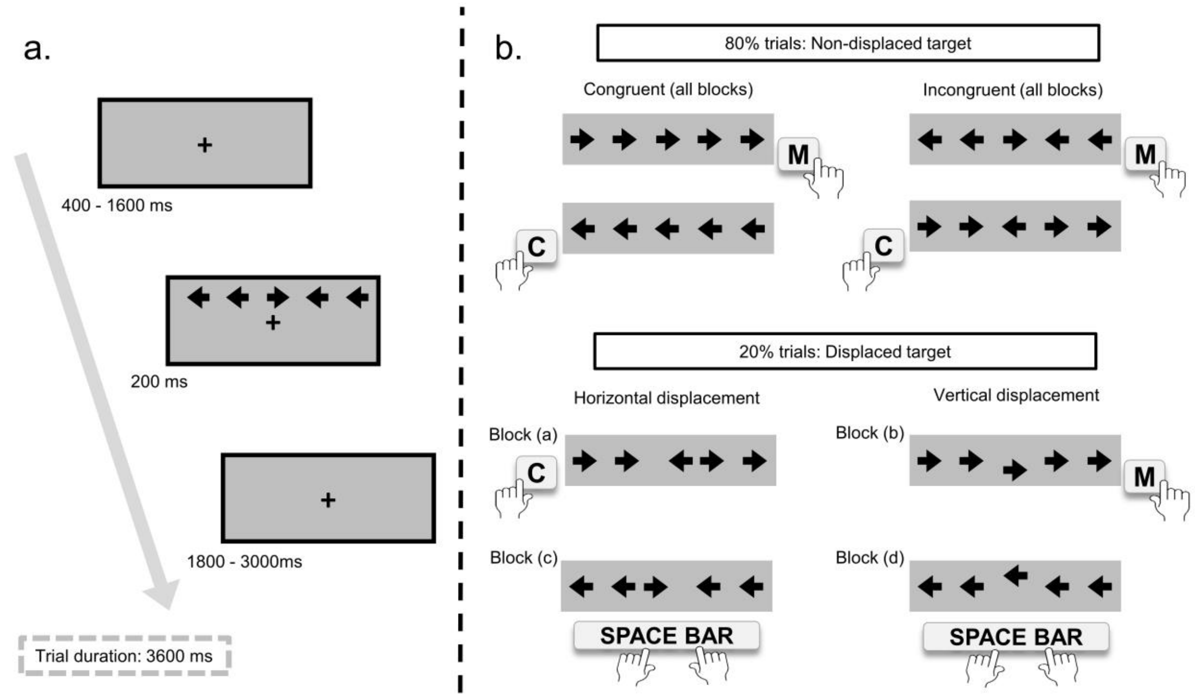

Fig. 2. Stimuli and timing for the experimental task. (a) Experimental procedure. The row of arrows could appear over or below the fixation point. Responses were allowed until 2000 ms since target appearance. (b) Examples of non-displaced target (congruent and incongruent) and displaced target (horizontal or vertical) trials. The pressed key beside or downside each example represents the correct answer in that trial.

Instructions were given before each experimental block. Participants were encouraged to focus on the fixation point at every moment. In all blocks, participants were instructed to perform the main flanker task. In the two blocks where participants should also perform the vigilance task, instructions highlighted that sometimes the central arrow could appear clearly displaced from the central position (either leftwards/rightwards in the horizontal condition, or upwards/downwards in the vertical one). In these cases, participants were asked to detect the displacement and to report it by pressing the space bar as soon as possible. Before starting each experimental block, participants performed a practice block (not included in the statistical analyses) of 16 trials (8 without the target displacement, and 8 with the –horizontal or vertical– target displacement), with the appropriate instructions and visual feedback according to the task or tasks to complete on each block.

Within each of the four experimental blocks, there were 80 trials (64 without and 16 with target displacement) presented in random order. The 64 trials without target displacement included eight repeated trials of each condition of the following factorial design: Congruency (congruent/incongruent) × Target direction (left/right) × Arrow string position regarding the fixation point (above/below). The two last factors were considered just for stimuli presentation, and only congruency was included in the statistical analysis. For the 16 trials with target displacement, one factor was added to the previous design, displacement direction (left/right or up/down, depending on the displacement condition).

Data analyses.

First, to ensure that participants understood the instructions of each experimental block, we inspected the percentage of displaced targets correctly detected (i.e., the hit rate of the vigilance task). As expected, participants did try to detect the target displacement in the blocks where it was required (horizontal displacement = 57.39%; vertical displacement = 75.01%), but not when they were encouraged to perform just the flanker task (both blocks = 0% of false alarms). This detection performance, better for the vertical displacement, is similar to the one observed with the vertical and horizontal versions of the ANTI-Vea (Luna et al., 2018).

Then, we proceeded to analyze participants' performance in the flanker task. Importantly, as in Experiment 1, only trials without target displacement were considered to analyze distractors' interference. Trials with incorrect responses in the previous trial (i.e., either an error in the flanker task or a miss in the vigilance task) were excluded (7.68%), to control the post-error slowing effect (Danielmeier & Ullsperger, 2011). In addition, and only for the analyses of RT, trials with incorrect responses (5.29%) and those with RT below 200 ms or above 1500 ms (1.15%) were excluded, following the same criteria of the study of Luna et al. (2018) and Experiment 1 of the present study. Next, two repeated measures ANOVA were conducted, one for RT and another for percentage of errors as dependent variables, with congruency (congruent/incongruent), task instructions (flanker/flanker and vigilance) and displacement direction (horizontal/vertical), as within-participant factors.

Results

Main effects for congruency (RT [F (1, 19) = 107.46, p < .001, η_p^2 = .85, (.67, .90)]; errors [F (1, 19) = 19.19, p < .001, η_p^2 = .50, (.15, .68)]), task instructions (RT [F (1, 19) = 132.22, p < .001, η_p^2 = .87, (.72, .92)]; errors [F (1, 19) = 26.47, p < .001, η_p^2 = .58, (.24, .74)]) and displacement direction (RT [F (1, 19) = 17.26, p < .001, η_p^2 = .48, (.13, .67)]; errors [F (1, 19) = 5.77, p = .027, η_p^2 = .23, (.00, .49)]) were statistically significant. Responses were slower and less precise for incongruent (RT = 609 ms, [583, 635]; errors = 7.34%, [5.34, 9.35]) than congruent trials (RT = 550 ms, [525, 576]; errors = 2.73%, [1.79, 3.67]); in trials with instructions for both flanker and vigilance tasks (RT = 642 ms, [615, 670]; errors = 7.34%, [5.60, 9.07]) than in those with just the flanker task's instructions (RT = 517 ms, [490, 544]; errors = 2.74%, [1.64, 3.83]); and in trials with the horizontal displacement (RT = 599 ms, [571, 627]; errors = 6.30%, [4.52, 8.08]) than in those with the vertical displacement (RT = 561 ms, [535, 586]; errors = 3.78%, [2.45, 5.08]).

Similarly, the two-way interactions Congruency × Displacement direction (RT [F (1, 19) = 34.88, p < .001, η_p^2 = .65, (.32, .78)]; errors [F (1, 19) = 27.25, p < .001, η_p^2 = .59, (.25, .74)]), Task instructions × Displacement direction (RT [F (1, 19) = 20.83, p < .001, η_p^2 = .52, (.17, .70)]; errors [F (1, 19) = 8.32, p = .009, η_p^2 = .30, (.02, .55)]), and Congruency × Task instructions (just for RT [F (1, 19) = 5.82, p = .026, η_p^2 = .23, (.00, .49)]; but not for errors [F (1, 19) = 2.07, p = .167, η_p^2 = .09, (.00, .36)]) were statistically significant.

More importantly, all the main effects and interactions described above were qualified by the predicted three-way interaction for both RT [F (1, 19) = 15.22, p < .001, η_p^2 = .44, (.10, .65)] and errors [F (1, 19) = 17.39, p < .001, η_p^2 = .48 (.13, .67)]. As can be observed in Fig. 3, while no Congruency × Displacement direction interaction was observed with the instructions to ignore the displacement (RT [F (1, 19) = 0.02, p = .885, η_p^2 = .00, (.00, .12)]; errors [F (1, 19) = 4.13, p = .056, η_p^2 = .18, (.00, .44)]), a clear interaction was observed when participants had to pay attention to it (RT [F (1, 19) = 25.81, p < .001, η_p^2 = .58, (.23, .73)]; errors [F (1, 19) = 24.49, p < .001, η_p^2 = .56, (.22, .72)]).

Pairwise comparisons confirmed as statistically significant the increment in the interference effect as a consequence of paying attention to the horizontal displacement (RT [F (1, 19) = 13.71, p = .001, η_p^2 = .42, (.08, .73)]; errors [F (1, 19) = 8.39, p = .009, η_p^2 = .31, (.02, .55)]), but not the reduction in the interference effect in the vertical condition (RT [F (1, 19) = 2.64, p = .120, η_p^2 = .12, (.00, .39)]; errors [F (1, 19) = 3.12, p = .093, η_p^2 = .14, (.00, .41)]).

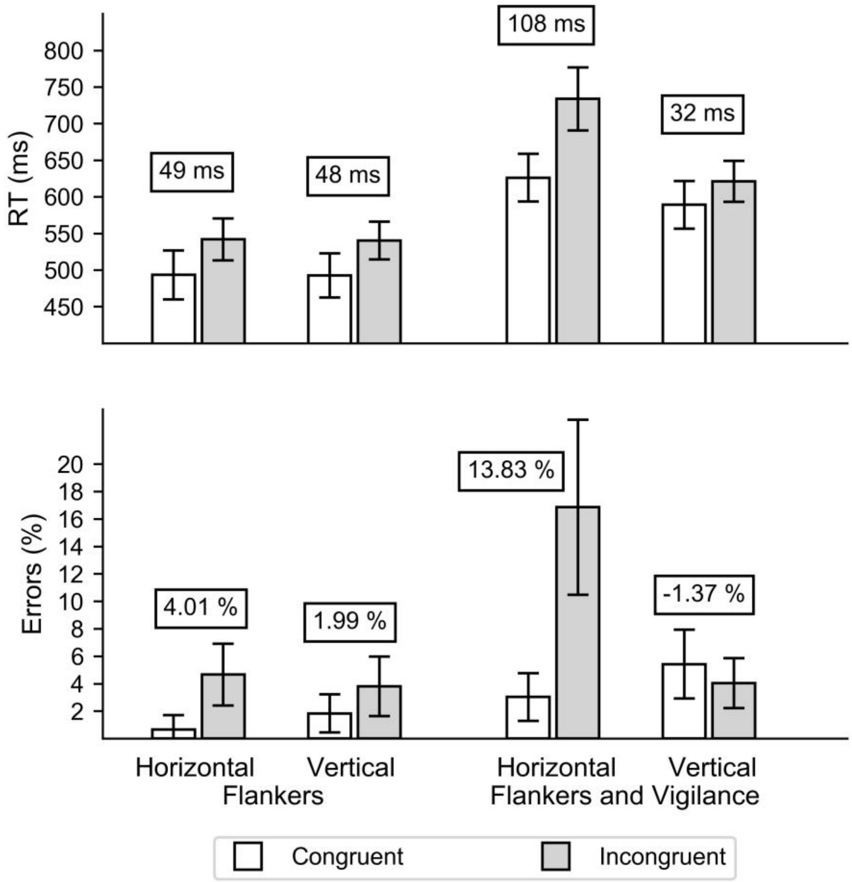

Fig. 3. Mean correct RT (superior panel) and percentage of errors (inferior panel) for congruency conditions in the main flanker task, as a function of the different attentional sets demanded in Experiment 1. The boxes over each pair of bars shows the interference effect (i.e. the difference between incongruent and congruent conditions) for that attentional set. Error bars represent 95% confidence intervals.

Experiment 3

In all the experiments reported so far, the vertical and horizontal displacements of the target were presented either in separate tasks (i.e., as in those reported in Experiment 1) or in different blocks of trials (i.e., the Experiment 2). The goal of the present experiment was to confirm whether the modulation of distractors’ interference as a function of the attentional set is still observed when both types of displacement are presented within the same block. As in

Experiment 2, the hypotheses and experimental design were also pre-registered in OSF (http://osf.io/wv9qz). We anticipated that the interference effect would be again close to 55 ms when performing only the flanker task. However, this effect would be reduced when attention was deployed to the vertical displacement and increased when the horizontal displacement had to be detected. Last, when the flanker task had to be performed whilst attempting to detect both the vertical and horizontal displacements, we anticipated an overall increase in the RT and errors. Nevertheless, as target selection would not be completely benefitted or hindered, the same interference size than when performing just the flanker task was expected.

Method

Participants.

Twenty four (16 women) undergraduate students from the University of Granada, Spain (age: *M* = 19.17, *SD* = 1.58) participated in this experiment. As in Experiment 2, sample size was estimated a priori using G*Power 3.1.9.2 (Faul et al., 2007). We estimated that the minimum sample size required to detect the effect size (η_p^2 = .44) of the three-way interaction observed in Experiment 2 of the present study (with RT as dependent variable), with a power of $1 - \beta$ =.95 and an alpha of .05, was 20 participants. Then, taking into account this estimation and to have one participant per sequence of blocks (see the Procedure and design section for details), we decided to collect data from 24 participants.

Procedure and design.

In this task, each of the four blocks included trials with the target horizontally displaced (15%), vertically displaced (15%), and not displaced (70%) from its central position. Participants were instructed to complete each block differently: (a) responding always to the direction the target pointed to (i.e., all the trials as a flanker task); (b) responding to the direction the target pointed to, while attempting to detect only its horizontal displacement; (c) responding to the direction the target pointed to, while attempting to detect only its vertical displacement; and (d) responding to the direction the target pointed to, while attempting to detect both horizontal and vertical displacements. For each participant, instructions to solve the blocks of trials were given in a different order, selected from the 24 possible sequences from the permutation of the four conditions.

The sequence and timing of events within each trial were the same as in Experiment 1. In addition, before starting the experimental trials, participants performed a practice block of 24 trials (8 with the target not displaced, 8 with the target vertically displaced, and 8 with the target horizontally displaced), with the appropriate instructions and feedback according to the task or tasks to complete on each block. Within each of the four experimental blocks, there were 104 randomly presented trials (72 without target displacement, 16 with the target horizontally displaced, and 16 with the target vertically displaced). Trials were selected from the same factorial design as in Experiment 1.

Data analyses.

One participant was excluded from the analyses due to an extreme average RT (i.e., 2.5 standard deviations above the mean). To verify the correct understanding of the instructions given for each block of trials, we inspected space bar responses to the horizontally or vertically displaced targets. Participants did not detect any infrequent displacement (i.e., 0% of space bar responses) when they were instructed to solve all the trials as a flanker task. When instructions set the detection of just the horizontal displacement (hits = 49.73%), participants also pressed the space bar on a small proportion of trials (11.68%) with the vertical displacement. Similarly, when participants were to pay attention just to the vertical displacement (hits = 64.95%), they also erroneously responded to the non-instructed displacement (i.e., the horizontal) in a small proportion of trials (2.99%). Last, when attempting to detect both displacements within the same block, the hit rate was higher for the vertical (81.25%) than for the horizontal displacement (50.00%) and, again, similar to the pattern of results observed with the ANTI-Vea task (Luna et al., 2018).

Importantly, as in the previous experiments, analyses were conducted on the same type of trials across the experimental blocks, i.e., those wherein the target was not displaced from its central position. Post-error trials (11.85%) were excluded from data analyses. For the RT analysis, we also removed trials with incorrect response (6.78%) and those with RT below 200 ms or above 1500 ms (0.97%). Next, two repeated measures ANOVA were conducted, one for RT and another for percentage of errors as dependent variables, with congruency (congruent/incongruent) and task instructions (flanker/flanker and vigilance to the horizontal displacement/flanker and vigilance to the vertical displacement/flanker and vigilance to both horizontal and vertical displacement) as within-participant factors.

Results

The main effect of congruency was statistically significant for both RT [F (1, 22) = 172.89, p < .001, η_p^2 = .89, (.76, .93)] and errors [F (1, 22) = 20.56, p < .001, η_p^2 = .48, (.16, .66)], with slower and less accurate responses for incongruent (RT = 619 ms, [587, 650]; errors = 8.91%, [6.74, 11.09]) than congruent trials (RT = 572 ms, [541, 605]; errors = 4.64%, [2.96, 6.32]). The main effect of task instructions was also statistically significant, for both RT [F (3, 66) = 51.49, p < .001, η_p^2 = .70, (.56, .77)] and errors [F (3, 66) = 21.54, p < .001, η_p^2 = .49, (.30, .60)]. As expected, compared to the single flanker task instructions (RT = 500 ms, [477, 523]; errors = 3.46%, [2.27, 4.64]), the overall RT (667 ms, [618, 715]) and percentage of errors (12.76%, [9.51, 16.02]) increased importantly when instructions asked participants to detect both the horizontal and vertical displacement of the target, both for RT

[F (1, 22) = 70.82, p < .001, η_p^2 = .76, (.53, .85)] and errors [F (1, 22) = 34.47, p < .001, η_p^2 = .61, (.30, .75)]. In the remaining task instructions, the pattern of results was the same as in Experiments 1 and 2. Responses were slower [F (1, 22) = 20.92, p < .001, η_p^2 = .49, (.16, .67)] and less precise [F (1, 22) = 9.90, p = .004, η_p^2 = .31, (.04, .54)] when participants were instructed to also pay attention to the horizontal displacement of the target (RT = 635 ms. [597, 674]; errors = 7.66%, [4.75, 10.58]), than when paying attention to the vertical displacement (RT = 580 ms, [550, 611]; errors = 3.22%, [1.56, 4.89]).

The modulation of interference by task instructions was statistically significant for errors [F (3, 66) = 6.54, p < .001, η_p^2 = .23, (.05, .36)] and marginal for RT [F (3, 66) = 2.65, p = .056, η_p^2 = .11, (.00, .23)]. As can be observed in Fig. 4, and confirming our hypotheses, interference was similar when ignoring any displacement (i.e., when performing only the flanker task) and when paying attention to both the horizontal and the vertical displacement of the target (both for RT and errors, Fs < 1, ps > .40), despite the overall increase in both RT and percentage of errors in the latter condition. In contrast, as in Experiment 2, a clear interaction was found when participants had to pay attention to one of the two displacements of the target (RT [F (1, 22) = 6.60, p = .018, η_p^2 = .23, (.01, .47)]; errors [F (1, 22) = 14.26, p = .001, η_p^2 = .39, (.08, .60)]).

In addition, an important reduction of the interference effect was observed when the attentional set required to stay vigilant to the vertical displacement of the target, in comparison to when instructions were to ignore any displacement (RT [F (1, 22) = 6.91, p = .015, η_p^2 = .24, (.01, .48)]; errors [F (1, 22) = 11.53, p = .003, η_p^2 = .34, (.05, .56)]). Finally, when participants were instructed to detect just the horizontal displacement of the target, in comparison to ignoring any displacement, the increment on the interference effect was marginal for errors [F (1, 22) = 4.07, p = .056, η_p^2 = .16, (.00, .41)], and not significant for RT [F (1, 22) = 0.05, p = .834, η_p^2 = .00, (.00, .14)].

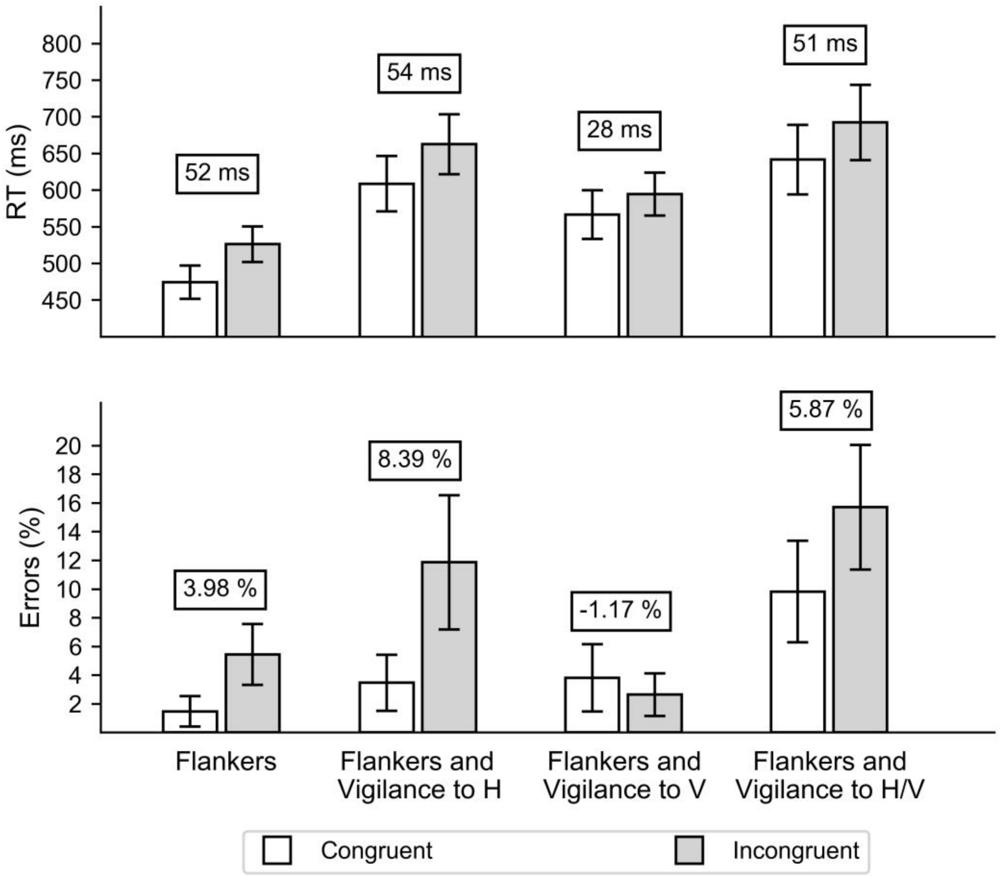

Fig. 4. Mean correct RT (superior panel) and percentage of errors (inferior panel) for congruency conditions in the flanker task, as a function of the different attentional sets demanded in Experiment 2. The boxes over each pair of bars shows the interference effect (i.e. the difference between incongruent and congruent conditions) for that attentional set. H = horizontal displacement. V = vertical displacement. Error bars represents 95% confidence intervals.

Summary of Results across Experiments

To summarize the results of the five experiments conducted so far (i.e., two in Luna et al., 2018, and the three experiments reported in the current paper), we collated all the individual-level data in two linear mixed-effects (LME) models, one for RT and another one for the percentage of errors. We expected that this high-powered comprehensive analysis would help us to determine whether interference increases when working memory is loaded with the attentional set to deploy attention to the horizontal displacement of the target and, on the other hand, whether there is a relevant reduction of interference when working memory is loaded with the attentional set to deploy attention to the vertical displacement. The analyses were conducted with the lme4 (Bates, Mächler, Bolker, & Walker, 2015) and lmerTest (Kuznetsova, Brockhoff, & Christensen, 2017) R packages (R Core Team, 2018).

To simplify the analyses, we first computed the mean interference effect (separately for RT and percentage of errors) per condition for each participant (*N* of observations = 296), and these interference scores were then entered as dependent variables in both models. Importantly, the attentional set was included as a categorical predictor with three different levels: (a) flanker task alone, (b) flanker task while staying vigilant to the horizontal displacement of the target, and (c) flanker task while staying vigilant to the vertical displacement of the target. To account for the statistical dependencies between data coming from the same experiments and the same participants, we added random intercepts for experiment and participant. The best fitting parameters of the models were found using restricted maximum likelihood. *P*-values were computed using Sattherthwaite's method.

Both LME models returned a significant intercept, showing that interference scores were different from zero when participants were instructed to perform only the flanker task [RT: t (10.68) = 9.81, $p < .001$; errors = t (292.99) = 5.04, $p < .001$]. More importantly, as can be observed in Fig. 5 and in line with our predictions, the instruction to pay attention to the horizontal displacement of the target increased interference scores [RT: t (67.42) = 5.16, $p < .001$; errors = t (264.45) = 6.93, $p < .001$], while instructions to pay attention to the vertical displacement of the target reduced interference [RT: *t* (66.33) = -3.40, *p* = .001; errors = *t* (264.98) = -4.28, *p* < .001].

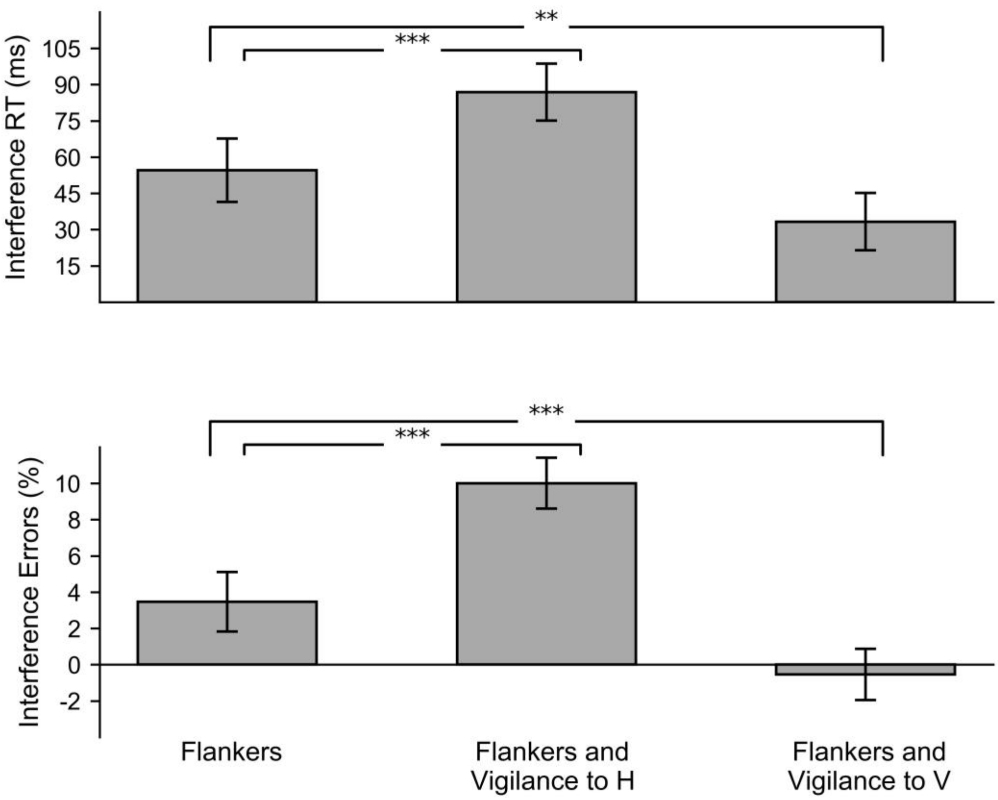

Fig. 5. Interference effect in RT (superior panel) and the percentage of errors (inferior panel) for the intercepts of the three different attentional sets. H= horizontal displacement, V= vertical displacement. *** = *p* < .001, ** = *p* < .01. Error bars show 95% confidence intervals.

Thus, our experiments clearly replicate previous findings of either increased interference (Lavie et al., 2004), reduced interference (Kim et al., 2005), or no effect of concurrent working memory load over interference (Gil-Gómez de Liaño et al., 2016). Furthermore, this pattern of results was observed in two pre-registered and high-powered studies, supporting the account that the nature of the attentional set maintained in working memory can be helpful, detrimental, or innocuous for the segregation of the target from the surrounding distractors and therefore for the interference they produce.

General Discussion

The present research aimed at clarifying under which circumstances cognitive control is affected by concurrent working memory load in dual tasking, leading to reduced or increased interference effects. Guided by previous findings from our lab, three experiments (i.e., Experiment 1 as a control of previous ‘serendipitous’ findings, and Experiment 2 and 3 following a pre-registered plan) were conducted to test the hypothesis that the nature of the attentional set maintained in working memory determines whether dual tasking is detrimental or even helpful for cognitively controlling interference. The observed pattern of results was clear: in a flanker task wherein the target and distractors were arrows aligned in a horizontal vector, interference increased substantially when attention was deployed simultaneously to detect an infrequent horizontal displacement of the target, but decreased considerably when it was focused in detecting a vertical displacement.

Whereas previous research has reported consistent evidence that the physical features of stimuli can either increase or reduce distractors’ interference (Kramer & Jacobson, 1991; Luo & Proctor, 2016; Richard et al., 2008; Shomstein & Yantis, 2002), it should be noted that the current findings cannot be explained by the perceptual horizontal or vertical distance of the target from distractors in the secondary task. In the present study, the differences observed in the interference effect were computed from trials that were perceptually identical, i.e., the trials wherein the target was not displaced in any direction from its central position. Still, distractors’ interference was particularly modulated in opposite directions under concurrent working memory load conditions. In particular, in the single task condition, the size of the observed interference was similar no matter whether the target was displaced horizontally or vertically on some trials. However, once working memory was loaded by the need to perform two tasks simultaneously, the unique difference between the two dual tasking conditions was the attentional set maintained in working memory. Thus, distractors’ interference was considerably increased when the attentional set overloaded the grouping dimension of target and distractors (i.e., horizontal), but it was importantly reduced with an attentional set directed to an orthogonal dimension (i.e., vertical), perhaps by helping to segregate the target from distractors.

There is a large body of evidence suggesting that dual tasking hinders performance due to an increase in distractors' interference (e.g., Marois & Ivanoff, 2005; Pashler, 1994; Watanabe & Funahashi, 2014). This pattern of results has been observed not only in cognitive control tasks, but also in other tasks (Helton & Russell, 2011; Kiss, Brueckner, & Muehlbauer, 2018; Röttger, Haider, Zhao, & Gaschler, 2017). A widely-accepted framework to explain these findings is the load theory of selective attention and cognitive control (Lavie et al., 2004). From this account, the increases of distractors' interference in dual tasking would be explained by the fact that a single and limited resources pool would be necessarily used for both maintaining active information in working memory and implementing control strategies to inhibit distractors information (de Fockert, 2013; Lavie et al., 2004). Therefore, attentional resources would be shared across concurrent tasks, overloading the processing capacity of the attentional system (Kanheman, 1973; Watanabe & Funahashi, 2014).

An alternative framework to account for the different circumstances under which concurrent working memory load can hinder or even benefit cognitive control is the multiple resources account (Kim et al., 2005). From this perspective, the limited pool of attentional resources can be assigned separately to the stimuli of the tasks at hand. Thus, if the working memory and selective attention tasks overload the processing of the target, then distractor interference is considerably increased. Instead, and critically, if the overload is related just to the information of the distractors, then selective attention enhances the target processing and, therefore, distractor interference is importantly reduced (Gil-Gómez de Liaño et al., 2010; Kim et al., 2005; Park et al., 2007).

Nevertheless, attempts to replicate the reduction of interference have not been consistent, with contradictory results leading some authors to question the possibility that concurrent working memory load can enhance selective attention (Gil-Gómez de Liaño et al., 2016, 2010). In the unsuccessful attempt of Gil-Gómez de Liaño et al. (2016) to replicate the findings from Experiment 3b in Kim et al. (2005), the authors objected to the small sample size (N = 10) and low number of trials (i.e., 20) per condition in the original study, and remarked the need of conducting replications and meta-analyses to resolve conflicting findings. Importantly, our experiments are free from the methodological shortcomings identified by Gil-Gómez de Liaño et al. Sample size was estimated a priori by power analyses, and the experimental tasks included enough repeated measures for each condition. Furthermore, and critically, both the increment and reduction of interference were consistently replicated, and confirmed with LME models.

We consider that the resource theories of selective attention mentioned above do not provide an adequate framework to account for the pattern of results reported in the current study. On the one hand, load theory cannot explain the fact that dual tasking did reduce distractors interference when participants maintained in working memory the attentional set to detect the vertical displacement of the target, neither can it explain the similar effect observed when the dual task referred to an attentional set to detect both the horizontal and vertical displacement. On the other hand, following the multiple resources theory, in the present study both the primary and secondary task overloaded the focus on the target and not on the distractors, with the attentional set to detect either the horizontal or the vertical displacement of the target. In this line, the multiple resources theory would predict the increment of interference observed when instructions demanded to detect the horizontal displacement, but cannot account for the reduction of interference observed in the vertical displacement condition, or the lack of effect in the vertical/horizontal condition. Therefore, it seems appropriate to consider that the specific attentional set induced by task-instructions and maintained in working memory in dual tasking situations is critical to either impair or enhance cognitive control (Goldfarb et al., 2011; Liefooghe et al., 2012; Wenke et al., 2014).

But, specifically, how is it that the attentional set kept in mind can modulate target selection in dual tasking? To begin with, note that the stimuli set of the present research overloads the stimuli features over a single dimension, i.e., the horizontal one. In particular: (a) the target and distracting arrows point in the horizontal sense (i.e., either to the left or right direction), (b) the string of arrows is horizontally distributed (i.e., as a horizontal vector), and (c) the response options are part of the horizontal dimension (i.e., the left or the right response key). All these dimensional characteristics jointly contribute to the attentional set kept in mind when performing the selective attention task. Importantly, we argue that the secondary task can modulate the attentional set either to segregate or boost the horizontal grouping dimension.

Thus, when the secondary task requires detecting a vertical displacement of the target, it implies a new dimension that is orthogonal to the horizontal grouping dimension of the main flanker task. In this particular circumstance, the need to deploy attention over this unique orthogonal dimension is, in our opinion, the critical factor that helps to segregate the target from the distractors, thus reducing interference. Interestingly, previous research has reported reduced interference in single task conditions wherein attention is deployed to a characteristic that breaks the grouping dimension of the target and distractors. For instance, the object-based modulation effect demonstrates that if stimuli are presented within separate background objects, interference is reduced if the background of the target is different to the one of distractors (i.e., a circle and rectangles, respectively) but not if all stimuli are presented over a similar background object (i.e., a single rectangle for each stimulus; Luo & Proctor, 2016).

A similar pattern is observed when grouping is broken at a more conceptual level as in the aforementioned study by Avital-Cohen & Tsal (2016). They observed that, in a flanker task wherein the target was the letter ‘S’ and distractors were the number ‘5’, interference was reduced when instructions anticipated the distractors to be of an opposite dimension (i.e., numbers) to the one of the target (i.e., letter), but not if instructions anticipated all stimuli to belong to the same grouping dimension (i.e., to perceive both target and distractors as letters). In the present research, making salient a vertical dimension broke the horizontal grouping of the flanker task, and led to reduced interference. In contrast, keeping in mind the intention to detect a horizontal displacement overloaded the horizontal grouping dimension of the flanker task resulting in an increased interference.

As discussed above, the multiple resources theory has been proposed as an adequate framework to account for both the increment and the reduction of distractors’ interference in dual tasking conditions. For instance, in the study conducted by Park et al. (2007), the participants completed either a single selective attention task (e.g., a same/different task on two faces embedded on two houses, which would act as distractors and also be the same or different) or a selective attention and working memory task simultaneously. Importantly, the working memory task could demand to maintain in working memory stimuli similar to the target (e.g., two faces previously presented; supposedly overloading target processing in dual tasking and increasing interference) or stimuli of the same kind as the distractors (e.g., two houses previously presented; thus diminishing target processing in dual tasking and reducing interference). However, the idea that interference is decreased by deploying separately attentional resources to the target and distractors between the main and the secondary task cannot explain the findings reported here. In the present research, in both dual tasking conditions (i.e., the horizontal and vertical detection tasks) instructions overloaded target processing (i.e., the direction the target pointed to and the detection of its displacement), but interference was only increased in the horizontal condition.

However, in our opinion, the findings reported by Park et al. (2007) might also be explained as a function of the attentional set kept in mind in the two dual tasking conditions rather than by the distribution of specialized resources. In particular, when the secondary task forced participants to keep in mind two stimuli of the same kind, but different from the ones on which participants had to perform the same/different task (i.e., all faces in our example), it was more difficult to segregate the relevant from the irrelevant stimuli. The similarity between the stimuli kept in mind (irrelevant for the same/different matching task) and the relevant ones presented in the screen would make more difficult to segregate targets (the two faces presented in the screen, in this example) from distractors (the two faces kept in mind and the two houses presented in the screen). However, when participants were set to keep in mind two stimuli irrelevant for the same/different matching task (two houses in the example), the similarity between all distractors (all houses) made it easier to segregate them from the target (faces in this case), therefore reducing interference.

Finally, it is important to note that our findings are exclusively based on spatial attention experiments, which might limits the generalizability of the explanation proposed here to other cognitive domains. Thus, it is possible that concurrent working memory load does not benefit cognitive control if target selection is measured in a non-spatial task. However, recent research has demonstrated that concurrent working memory load does not hinder cognitive control when target selection is assessed in an auditory task. In a sequence of four experiments, Moss, Kikumoto, & Mayr (2020) observed that interference did not increase (i.e., no effect on RT and a small increase in the errors rate) when participants performed an auditory Stroop task while completing a visual change detection task. In line with the results reported here, it seems that if the secondary task (i.e., the visual change task in the cited study) does not deploy attention to a relevant dimension for target selection, then cognitive control is not hindered in dual tasking conditions (Moss et al., 2020). Nevertheless, further research is still necessary to support the hypothesis that cognitive control is not impaired in dual tasking when the secondary task does not overload the grouping dimension of target and distractors in the main task. In particular, future studies wherein cognitive control is assessed in non-spatial domains seems necessary to generalize our hypothesis beyond the spatial domain.

To conclude, dual tasking has a cost that is revealed as slower responses and higher error rates in general. However, at variance with resources theories, the current research shows that increasing working memory load does not always lead to larger distractor interference. Rather than the limit of attentional resources, it seems that it is the nature of the mindset maintained in working memory what is critical to benefit or hinder target selection. Thus, cognitive control is boosted when the attentional set instructed helps to segregate the target from its grouping with distractors. Conversely, if the attentional set overloads the grouping of stimuli, interference becomes stronger. Therefore, the difficulty to perform two tasks at once can be substantially reduced or increased, depending on the particular attentional set maintained in working memory. This new account can easily explain the results reported in the current paper and those previously reported in the literature.

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