Central Executive and Target Selection in Visual Working Memory

Francéia Veiga Liedtke[1]
Juliana Burges Sbicigo[1]
Laura Tamborindeguy França[1]
Ana Luiza Tonial[1]
Alexandre de Pontes Nobre[1]
Jerusa Fumagalli de Salles[1]

[1]*Universidade Federal do Rio Grande do Sul, Porto Alegre, Rio Grande do Sul, Brasil*

Abstract
The goal of this study was to investigate if the selection of external information for storage in visual working memory requires control by the central executive when the categorization of targets is guided by instructions. The design was experimental 3 (concurrent task) x 2 (instruction). Forty-eight university students saw eight colored shapes, four of them surrounded by square outlines. Memory was assessed using a recognition task. Targets varied with instructions: targets were presented within squares in the first block and outside squares in the second block. There were three concurrent tasks: no task, articulatory suppression, and backward counting. Performance was measured by hits, false alarms, corrected recognition, and sensitivity (A'), compared using within-subject ANOVAs. Results showed a main effect only for concurrent task, with lower performance in the backward counting condition for all measures. These results suggest that the central executive does not control the perceptual filter, corroborating earlier results.
Keywords: Attention, visual working memory, central executive, cognitive psychology, experimental psychology

Executivo Central e Seleção de Alvos na Memória de Trabalho Visual

Resumo
O objetivo deste estudo foi investigar se a seleção de informações externas para manutenção na memória de trabalho visual requer controle do executivo central, quando a categorização de alvos depende de instrução. O delineamento foi experimental três (tarefa concorrente) x duas (instrução). Participaram 48 universitários. Os participantes viam oito formas coloridas, quatro delas dentro de quadrados. A memória foi avaliada por reconhecimento. Os alvos dependiam de instrução: no primeiro bloco estavam dentro de quadrados e no segundo, fora de quadrados. Havia três tarefas concorrentes: sem tarefa, supressão articulatória e contagem inversa. O desempenho foi avaliado por acertos, alarmes falsos, taxa de reconhecimento correto e índice de sensibilidade A', comparados por meio de ANOVAs intrassujeitos. Os resultados mostraram apenas efeito principal da tarefa concorrente, com menor desempenho na condição contagem inversa em todas as medidas. Esse resultado sugere que o executivo central não controla o filtro perceptual, corroborando resultados anteriores.
Palavras-chave: atenção; memória de trabalho visual; executivo central; psicologia cognitiva; psicologia experimental

Ejecutivo Central y Selección de estímulos por la Memoria de Trabajo Visual

Resumen
El objetivo fue investigar si la selección de información externa para el mantenimiento de la memoria de trabajo visual requiere un control del ejecutivo central, cuando la categorización de los estímulos depende de instrucciones. El diseño fue experimental 3 (tarea concurrente) x 2 (instrucción). Los 48 estudiantes universitarios participantes vieron ocho formas de colores, cuatro de ellas dentro de cuadrados. La memoria se evaluó por reconocimiento. Los estímulos dependían de la instrucción: en el primer bloque estaban dentro de los cuadrados, y en el segundo, fuera de ellos. Hubo tres tareas recurrentes: ninguna tarea, supresión articulatoria y conteo inverso. El rendimiento se evaluó mediante aciertos, falsas alarmas, tasa de reconocimiento correcto e índice de sensibilidad A', mediante ANOVAs intrasujeto Los resultados mostraron solo el efecto principal de la tarea concurrente, con menor rendimiento en la condición de conteo inverso en todas las medidas. Los resultados sugieren que el ejecutivo central no controla el filtro perceptual, corroborando resultados anteriores.
Palabras clave: Atención, Memoria de Trabajo Visual, Ejecutivo Central, Psicología Cognitiva, Psicología Experimental.

Introduction

Working memory (WM) is a limited capacity system that provides temporary storage and manipulation of information during performance of complex tasks (Baddeley, 2000). Visual working memory (VWM) provides temporary storage of information in the visual domain. In the multicomponent model of working memory (Allen, Hitch, & Baddeley, 2019), VWM comprises a perceptual filter, a visuospatial component, an

http://dx.doi.org/10.1590/1413-82712022270404

episodic buffer, and a central executive (CE). Experimental studies (e.g., Allen, Castellà, Ueno, Hitch, & Baddeley, 2015) support the existence of two distinct but complementary subsystems in VWM: a visual subsystem that processes visual features such as color or shape; and a spatial subsystem, which processes object location.

WM is closely related to attention (Oberauer, 2019), which selects, modulates, and maintains task-relevant information. Attention may be categorized according to the origin of the information: external attention handles sensory information, while internal attention handles internally generated representations (Chun, Golomb, & Turk-Browne, 2011). WM is located in the interface between those two attentional systems: new information enters into VWM after being selected by external attention and is maintained in the temporary store by internal attention (Allen, Baddeley, & Hitch, 2014; Chun et al., 2011).

In the speculative model of WM (Baddeley, 2012) and its evolution to the VWM model by Hu and colleagues (Hu, Hitch, Baddeley, Zhang & Allen, 2014; Hu et al., 2016), VWM includes an external attentional filter (perceptual filter), an internal attentional resource (central executive – CE), and two temporary stores (visuospatial component and episodic buffer). The perceptual filter selects new visual information through stimulus-driven attention. This component allows the passage of plausible items, i.e., those that have visual features (e.g., color or shape) matching the targets (Ueno, Allen, Baddeley, Hitch, & Saito, 2011a; Hu et al., 2016; Hu et al., 2014).

The CE controls internal attention, which maintains representations in their respective temporary stores through constant updating (Hitch et al., 2019). Recent items, or those that are tested more often in a task, do not actively recruit this component (Hitch et al., 2019; Atkinson, Berry, Waterman, Baddeley, Hitch, & Allen, 2018). On the other hand, maintaining representations that are prioritized by instructions requires resources from the CE, which allocates goal-directed attention to prevent item fragmentation, caused by time or by competition from new items (Allen et al., 2014; Hu et al., 2014; Hu et al., 2016; Hitch, Hu, Allen,& Baddeley, 2018).

The episodic buffer stores integrated objects in a format that is available to consciousness. This component has been linked to the focus of attention (FoA) proposed by some working memory models (e.g., Cowan, 2011): both consist of a region in memory that is accessible and privileged, but also limited, unstable, and vulnerable to fragmentation (Hu et al., 2014; Hitch et al., 2018; Hitch et al., 2019). Usually, the episodic buffer stores recent items, but it may also store up to two pieces of information related to goals prioritized by instructions (Hu et al., 2016; Hitch et al., 2018, Hitch et al., 2019). The visuospatial component stores partial information before they undergo total fragmentation (Hitch et al., 2019).

The environment presents the visual system with much more information than the FoA of VWM can maintain (Hitch et al., 2018). Often, targets must be selected among distractors to prevent VWM from being overloaded (Vogel, MacCollough, & Machizawa, 2005). Some studies propose that individual differences in tasks that require maintaining and manipulating visual information are a result of failures in that process (Vogel et al., 2005; McNab & Kligberg, 2008; Emric h& Busseri, 2015; Liesefeld, Liesefeld, & Zimmer, 2014). Although the CE is generally considered to maintain representations in VWM, its role in the selection of visual information entering VWM is not clear.

Hu et al. (2014, 2016) hypothesized that the CE controls the perceptual filter, allowing the passage of relevant items and excluding irrelevant ones. However, experiments employing suffixes suggest that such selection occurs automatically, without control by the CE (Hitch et al., 2019; Hu et al., 2016). On the other hand, the CE seems to maintain relevant items in the FoA, protecting them from fragmentation (Hu et al., 2016). Hence, what items are maintained in the FoA is determined by two independent factors: stimulus-driven attention, which automatically selects stimuli with plausible features to enter the FoA through the perceptual filter; and goal directed-attention, controlled by the CE, which maintains relevant items in the FoA (Hitch et al. 2018; Hu et al., 2016; Hitch et al., 2019).

To investigate if the CE controlled the perceptual filter, Allen et al. (2017) analyzed the effect of distractors and secondary tasks on a visual recall task. They conducted seven experiments examining memory for colors, unfilled shapes and colored shapes. Participants performed a secondary task (either AS or BC) in different blocks. Targets were presented along with distractors in some trials and without distractors in others. In experiment 3, targets and distractors were randomly positioned on the screen, with targets being distinguished from distractors by surrounding square outlines for ⅓ of the presentation time. Performance was measured by verbal responses to the spatial position of the stimuli. They found main effects of stimulus type (color > unfilled shapes > colored shapes), secondary task (AS > BC), and presence of distractors (absent > present) on accuracy, and no interaction between the independent variables. The findings of this and other experiments are in line with those from Hu et al. (2016) showing that the CE does not control the perceptual filter — that is, the CE does not prevent the entrance of irrelevant information. According to Allen et al. (2017), the main effect of secondary task can be attributed to the fact that those tasks consume attentional resources necessary for encoding, maintaining and retrieving information from VWM. A similar effect was observed in previous experiments in which targets were presented simultaneously (Allen et al., 2006; Allen et al., 2012) or sequentially (Allen et al., 2014) in the absence of distractors.

In the experiments by Allen et al. (2017), participants were not explicitly told which stimuli were targets and which were distractors. Because a large number of stimuli were presented for a short time on each screen, the ability to direct attention to the squares should facilitate the selection of correct stimuli. For this reason, the findings of Allen et al. (2017) might be a consequence of experimental features not related to control by the CE, such as the use of squares to distinguish targets and distractors. Because targets and distractors were visually dissimilar, inhibition by the perceptual filter might have been facilitated when discriminating targets from distractors (Hu et al., 2014).

Since the FoA is limited, a mechanism through which the CE controls the selection of information is necessary, particularly when goal-directed attention is employed. Directing internal attention to goal-relevant items requires control by the CE (*goal-directed attention*). Considering the hypothesis by Hu et al. (2014; 2016), this component is likely to be engaged in the control of external attention as well, when a goal is specified, e.g., by instructions. Thus, it is possible that control mechanisms influence processing of information in VWM from the perceptual filter up to maintenance in the FoA of VWM.

The goal of this study was to investigate if selection of information in VWM requires CE control through goal-directed attention, when the categorization of targets and distractors depends on experimental instructions. We created an experimental task based on experiment 3 by Allen et al. (2017), with the difference that the instructions determined which stimuli were surrounded by square outlines (targets or distractors). In the first block, the square outlines surrounded targets, whereas in the second block they surrounded distractors. With this manipulation, we aimed to direct attention according to a goal in the first block and set a new goal in the second block, thus engaging goal-directed attention, which requires control by the CE.

If the selection of external information did not require controlled processes, we expected a reduction in performance due to the entry of distractors into VWM in the condition in which targets were presented outside squares, irrespective of concurrent task. Our rationale was that, since in this condition stimuli that were targets in the previous block became distractors, participants would need to change the objects of their attention according to a new goal. Additionally, if the CE controlled the maintenance of internal representations, we expected a larger dual-task cost when participants performed BC, compared to conditions where they performed AS or NT, in both conditions (Allen et al., 2014; Hu et al., 2016), that is, regardless of instruction. Finally, if the CE controlled the perceptual filter, we expected an interaction between instruction and concurrent task, with a larger cost due to BC in the condition of targets presented outside squares compared to the condition in which they were presented within squares.

Methods

Participants

Forty-eight undergraduate students (30 female) were recruited, aged 18 to 26 years of age (M = 20.7, SD = 2.12), from public and private universities in Porto Alegre, Southern Brazil. Participants were a convenience sample recruited from classrooms and social media using an online questionnaire to collect demographic and health data. They were instructed to sleep properly and avoid intake of stimulating, depressor, or hallucinogenic substances on the day before the experiment. Individuals with uncorrected visual impairments and those who had used any psychoactive substance in the 24 hours before the experiment were excluded.

Materials

The experimental task was programmed and run in Python using the Psychopy library (Peirce, 2007). Participants sat at a distance of 50 cm from a 14-in screen with 1366x768 resolution and a 60 Hz refresh rate. Stimuli were presented on a white background. All stimuli measured 0.8 visual degrees in height and width and were chosen from a pool of 64 colored shapes built from a combination of eight shapes (arc, chevron, circle, cross, diamond, flag, star, and triangle) and eight colors (blue, grey, green, purple, red, black, yellow, and turquoise). The same stimulus was never shown twice on the same screen.

Examples of target screens are shown in Figure 1. Each target screen consisted of eight shapes drawn in random locations around the center of the screen within an invisible 4x4 matrix. Four of the eight shapes, chosen randomly, were surrounded by a black square outline 2.71°in size. The response screen consisted of a single shape presented in the center of the display, which the participant had to recognize as a target or a distractor.

Procedure

The experiment was conducted in a room with a reduced number of distractors. Participants were initially asked if they had followed all recommendations regarding sleep and substance intake using a checklist. Then, they answered the Self-Reporting Questionnaire (SRQ-20), adapted from Gonçalves, Stein, and Kapczinski (2008). This screening scale was used to detect mental disorders. Participants who scored at or above the cutoff point of 7 (Gonçalves, Stein & Kapczinski, 2008) were excluded from the analysis. Afterwards, they received instructions about the experiment. The whole testing session lasted approximately 45 minutes. All participants signed an informed consent form before testing. This study was approved by the Ethics Committee of the Institute of Psychology at the Federal University of Rio Grande do Sul (protocol n. 3.320.424).

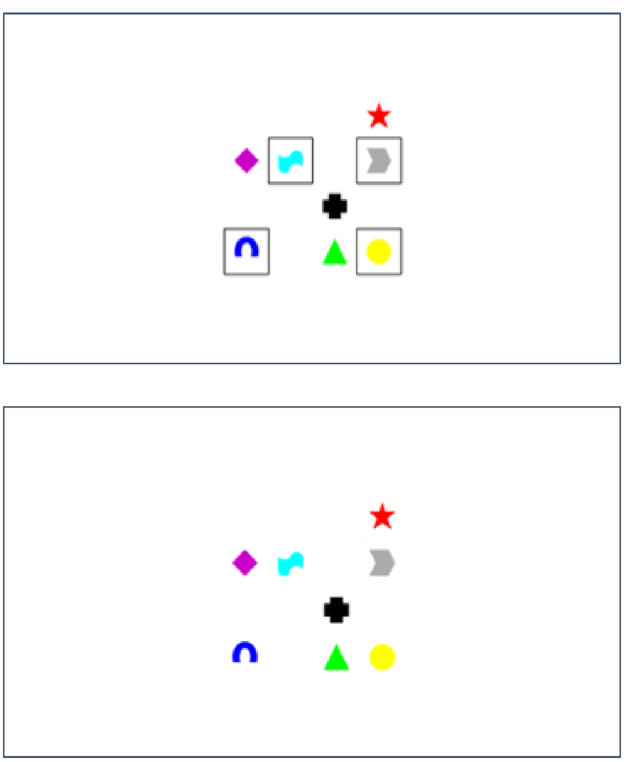


Figure 1. Schematic illustration of target screens. RGB values of the colors: blue (0, 0, 254), grey (171, 171, 171), green (0, 255, 1), purple (201, 0, 200), red (254, 0, 0), black (0, 0, 0), yellow (255, 255, 1), and turquoise (1, 255, 255).

The experiment followed a 3x2 design, with concurrent task (AS, BC, and NT) and instruction (within squares – WS, and outside squares – OS) as factors. The main task was performed in three blocks. In each block, participants performed only one of the concurrent tasks. The order of blocks was counterbalanced across participants. Within each block, the order of instructions was fixed – WS, then OS. Each block comprised 64 trials, 32 trials for each type of instruction. Before the experiment began, participants performed a practice block with six trials in the WS condition and no concurrent task (condition NT).

Instructions for both the main task and the secondary task were presented in Portuguese on the screen; the experimenter remained in the room for additional instructions if necessary. In the WS condition, the instructions read: "Now, pay attention ONLY to the shapes WITHIN SQUARES. In the response screen, press YES if the shape was presented WITHIN squares and NO if it was presented OUTSIDE squares". In the OS condition, they were presented the following instructions: "Now, pay attention ONLY to the shapes OUTSIDE squares. When the response screen appears, press YES if the shape was presented OUTSIDE squares and NO if it was presented WITHIN squares".

For the concurrent task, the instructions in condition NT read: "In this block, when you see a number, read that number aloud. For example, if you see the number 12, you must read aloud: 'twelve'". In condition AS, the instructions were: "In this block, when you see a number, say that number aloud repeatedly until you see the response screen. For example, if you see the number 12, you must repeat: 'twelve, twelve, twelve…' until the response screen appears". In condition BC, the instructions read: "In this block, when you see a number, count aloud backwards by threes starting from that number, until you see the response screen. For example, if you see the number 17, you must count: 'fourteen, eleven, eight, five…' until the response screen". In all conditions, the experimenter ensured that participants understood the instructions. In condition BC, counting accuracy was registered in a form by scoring a point for each correct response.

Trial sequence is depicted in Figure 2. All trials started with the presentation of a random two-digit number, which remained on the screen for 1500 ms. Then, a fixation cross was shown in the center of the screen for 500 ms, followed by a blank screen for 250 ms. Afterwards, targets and distractors were presented for 1500 ms, during which four shapes were surrounded by black square outlines for 500 ms. A blank screen followed which lasted 1000 ms. Finally, the response screen was shown, with a shape at the center.

The stimulus in the response screen (test stimulus) was always one of the stimuli shown in the target screen. The test stimulus was chosen from the stimuli within squares in half of the trials, and from the stimuli outside squares in the other half. Participants responded whether the shape was a target, according to the instruction for that block (WS or OS), by pressing keys labelled YES or NO on a numeric keypad, using the index or middle fingers of the right hand, respectively.

Data analysis

Accuracy in the recognition task was computed for each combination of secondary task and instruction. The data were analyzed using signal detection theory (Stanislaw & Todorov, 1999). Trials in which the test stimulus was a target (i.e., presented within squares in condition WS, or outside squares in condition OS) were considered signal trials; those in which the test stimulus was a distractor (stimuli within squares in condition OS and outside squares in condition WS) were considered noise trials. In target trials, YES responses were categorized as hits, and NO responses as misses. In noise trials, YES responses were considered false alarms and NO responses were considered correct rejections.

We computed H – the probability of responding YES on signal trials – as the ratio between number of hits and number of signal trials. FA, the probability of responding YES on noise trials, was computed as the ratio between number of false alarms and number of noise trials. As in previous VWM studies that assessed memory using recognition tasks (Allen et al., 2006; Allen et al., 2014; Ueno et al., 2011a; Allen et al., 2012), corrected recognition was computed by subtracting FA from H for each participant. To measure the overlap between signal and noise, i.e., sensitivity,

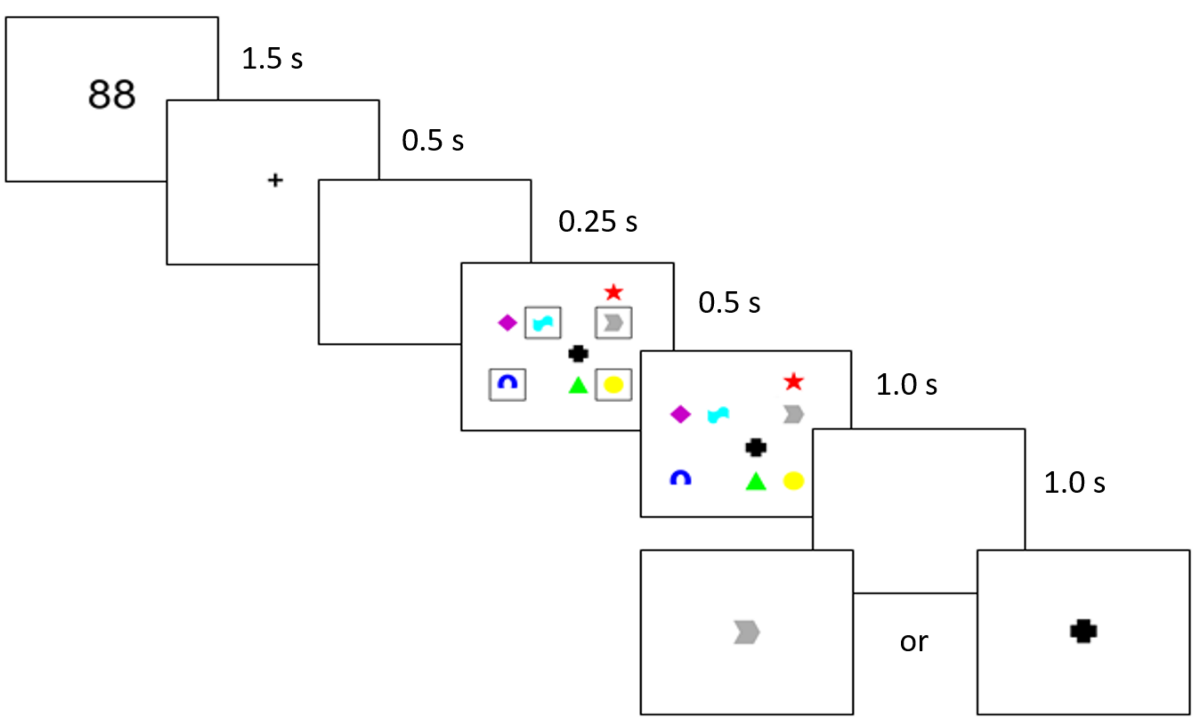


Figure 2. Schematic illustration of a trial sequence (adapted from Allen et al., 2017).

we calculated the A' index using formulas described by Stanislaw and Todorov (1999).

Descriptive statistics (means and standard deviations) were computed for each experimental condition. We conducted 3 (concurrent task: NT x AS x BC) x 2 (instruction: WS x OS) repeated-measures ANOVAs for each measure. The level of significance adopted was 5%. All analyses were run in SPSS version 25 (IBM, Armonk, NY, USA).

Results

Performance in the recognition task was measured by H, FA, corrected recognition (H-AF), and A'. Means and standard deviations for each measure in each experimental condition are shown in Table 1. We conducted 3x2 repeated-measures ANOVAs for each measure with concurrent task and instruction as factors.

Hits and false alarms

Results showed a similar pattern of results for all dependent variables. For hits, there was a main effect of concurrent task, $F(2,46) = 62.68$, MSE = 1.74, $p < .001$, $\eta_p^2 = .57$; but no effect of instruction, $F(1,46) = 2.92$, MSE = 0.05, $p = .09$, $\eta_p^2 = .06$; and no interaction between concurrent task and instruction, $F(2,46) = 2.68$, MSE = 0.04, $p = .07$; $\eta_p^2 = .05$. Participants scored less hits in condition BC than in conditions NT and AS. Scores in conditions NT and AS did not differ significantly. For false alarms, there was a main effect of concurrent task, $F(2,46) = 52.08$, MSE = 0.82, $p < .001$, $\eta_p^2 = .53$; but no effect of instruction, $F(1,46) = 0.60$, MSE = 0.00, $p = .444$, $\eta_p^2 = .01$; and no interaction, $F(2,46) = 0.31$, MSE = 0.00, $p = .737$, $\eta_p^2 = .01$. Participants produced more false alarms in condition BC than in conditions NT and AS. There was no difference in number of false alarms between conditions NT and AS.

Corrected recognition (H-AF). For corrected recognition, there was a main effect of concurrent task, $F(2,46) = 127.34$, MSE = 4.96, $p < .001$, $\eta_p^2 = .73$; but no effect of instruction, $F(1,46) = 1.15$, MSE = 0.03, $p = .289$, $\eta_p^2 = .02$; and no interaction, $F(2,46) = 0.97$, MSE = 0.02, $p = .384$, $\eta_p^2 = .02$. Pairwise comparisons showed that participants scored lower for concurrent task BC than for NT or AS ($p < .001$). Performance in the latter two conditions did not differ significantly. Figure 3 displays corrected recognition by condition.

Sensitivity index (A'). An ANOVA showed a main effect of concurrent task, $F(2,46) = 96.05$, $MSE = 1.00$, $p < .001$; $\eta_p^2 = .67$); but no effect of instruction, $F(1,46) = 0.00$, $MSE = 0.000003$, $p = .983$; $\eta_p^2 = .00$); and no interaction, $F(2,46) = 0.001$, $MSE = 0.002$, $p < .744$; $\eta_p^2 = .006$). Sensitivity was lower for concurrent task BC than for concurrent tasks NT and AS ($p < .001$) and did not differ between the latter two tasks.

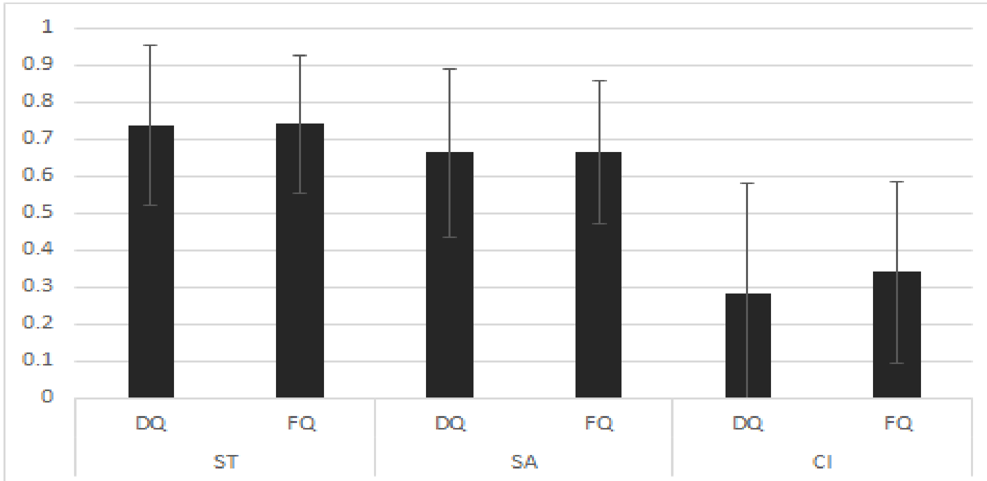
Discussion

In this study, we investigated the role of the CE in the selection of relevant information that passes

Table 1.
Means and Standard Deviations for the Dependent Variables by Concurrent Task and Instruction

Concurrent task	NT		AS		BC	
Instruction	WS	OS	WS	OS	WS	OS
H	0.81[a]	0.82[a]	0.75[a]	0.76[a]	0.53[b]	0.60[b]
	(0.09)	(0.14)	(0.18)	(0.16)	(0.23)	(0.21)
FA	0.08[a]	0.08[a]	0.09[a]	0.10[a]	0.24[b]	0.26[b]
	(0.09)	(0.08)	(0.10)	(0.09)	(0.18)	(0.17)
(H-AF)	0.74[a]	0.74[a]	0.66[a]	0.66[a]	0.28[b]	0.34[b]
	(0.22)	(0.19)	(0.23)	(0.19)	(0.29)	(0.24)
A'	0.77[a]	0.77[a]	0.72[a]	0.71[a]	0.57[b]	0.58[b]
	(0.13)	(0.13)	(0.14)	(0.12)	(0.09)	(0.10)

Note. NT WS=no task, attend stimuli within squares; NT OS= no task, attend stimuli outside squares; AS WS= articulatory suppression, attend stimuli within squares; AS OS=articulatory suppression, attend stimuli outside squares; BC WS= backward counting, attend stimuli within squares; BC OS= backward counting, attend stimuli outside squares; H= Hits; FA= False Alarms; H-AF= corrected recognition; A' = sensitivity index; [a, b] = means followed by identical letters are not significantly different at alpha = 5%.



Note. NT = No concurrent task; AS= Articulatory suppression; BC = Backward counting; WS = Within squares; OS= Outside squares.

Figure 3. Corrected recognition (H-FA) in the main task, by concurrent task and instruction.

through the perceptual filter, when the categorization of stimuli as targets or distractors is determined by instructions. We manipulated two independent variables. The first was the type of concurrent task participants performed: no task (NT), articulatory suppression (AS), or backward counting (BC). The second was the instruction for the main task: attend figures in squares (WS) or attend figures outside squares (OS). The dependent variables analyzed were hits (probability of target recognition – H), false alarms (probability of distractor recognition – FA), corrected recognition (H – FA), and sensitivity, as indexed by A' (overlap between signal and noise).

The impact of BC on all dependent variables under both instruction conditions suggests that the CE exerts control over selection of internal information. Several studies (e.g., Allen et al., 2006, 2014; Postma & De Haan, 1996) observed that performance in attentionally demanding tasks is impaired by concurrent BC tasks. AS is thought to occupy the verbal storage, imposing minimal demands on executive resources, while BC engages both the phonological loop and the CE, presumably because, in this task, participants have to both maintain and manipulate verbal representations in WM. Therefore, whereas AS is expected to have a negligible impact on concurrent attentional tasks compared to when no secondary task is performed (NT condition), BC consistently reduces performance on concomitant attentional tasks (Allen et al., 2017).

In line with this, we found a main effect of concurrent task on performance (hits, false alarms, and corrected recognition) and on the sensitivity index A'. Performance in the main task was worse (smaller number of hits and more false alarms) with BC as secondary task than with AS or NT. Hits, false alarms, and corrected recognition in conditions NT and AS were comparable to those observed in previous experiments that included no distractors (Allen et al., 2006; Allen et al., 2012). On the other hand, BC consumed resources from the CE, which impaired performance in the main task, resulting in worse target recognition (smaller H), distractor rejection (larger FA), and corrected recognition (smaller H-AF). Moreover, in this condition, sensitivity (A') was considerably smaller. The values of A' obtained in condition BC indicate a decrease in the ability to discriminate targets from distractors: we observed values close to 0.5, indicating that decisions about test stimuli were almost random (Stanislaw & Todorov, 1999). Thus, participants were apparently able to efficiently select items for storage in VWM in conditions AS and NT. In condition BC, the impact of the concurrent task on performance appears to be due to interference in selection by internal attention and maintaining information in WM. The CE may be responsible for carrying out some discriminations, allocating more attentional resources to the targets to maintain them in the FoA, which improves memory for those targets. Since attentional resources are limited, items that are not prioritized receive less attention. This selection process can be executed in conditions AS and NT, but not BC, which demands more resources from the CE. This might explain the reduction in performance and sensitivity in the main task in condition BC. Hence, the manipulation employed in the current experiment suggests that selection of external information for VWM directed by goals demands resources from external attention; whereas maintaining such information requires an internal control mechanism: the CE. Nonetheless, the absence of interaction between instruction and concurrent task suggests that the CE does not control the passage of information through the perceptual filter, contrary to our initial hypothesis. This result corroborates the findings of Hu et al. (2016) and Allen et al. (2017) about the relationship between internal and external attention in VWM. Earlier studies on selective attention conclude that external and internal attention interact (Konstantinou et al., 2014; Lavie, 2010), whereas VWM studies (e.g., Allen et al., 2017; Hu et al., 2016) suggest that they function independently. This discrepancy may be due to the type of processing required by tasks employed in studies on selective attention and in studies on VWM. Konstantinou et al. (2014) examined the effect of perceptual load and cognitive load in a main task involving response interference. Such tasks involve not only attentional selection of targets among distractors, but also interference of associations between distractors and targets on the selection of responses to targets (Forster, Robertson, Jennings, Asherson, & Lavie, 2014), a processing stage that occurs following perceptual analysis (Pashler, 1998). Considering that those tasks rely on response inhibition, which consume executive resources (Foster et al., 2014), allocating executive resources to demanding secondary tasks should indeed lead to a reduction in performance in the main task. Conversely, in Allen et al. (2017), as well as in the current experiment, the main task required perceptual analysis and maintaining stimuli in working memory but did not involve conflicting responses evoked by stimuli incongruent with the target. Thus, the difference between results from studies on selective attention and studies on VWM may be a result of the type of task employed in each group of studies: perceptual attention studies employ tasks that engage response inhibition (which requires executive resources), while tasks used in VWM usually do not. This is an alternative explanation to the one proposed by Allen et al. (2017), who suggested that cognitive load and perceptual load interact in selective attention tasks but not in VWM tasks. Given the results from this study and those of Baddeley and colleagues (Hu et al., 2014; Hu et al., 2016; Allen et al., 2017), in VWM the external attention filter (perceptual filter) and internal attention resources (central executive) appear to be independent. In VWM, distinct levels of internal attention are allocated to specific items, determined by the differential value attributed to the information (Atkinson et al., 2018; Hitch et al., 2019). The results reported here support the hypothesis that there is a region in VWM in which relevant items are stored (FoA), which have a high probability of being remembered. Plausible visual information is captured automatically by the external attention filter (Allen et al., 2014; Allen et al., 2016). In the multicomponent model of working memory, this store mechanism may correspond to the episodic buffer (Hitch et al., 2019). In the FoA, the CE allocates distinct quantities of attention to the targets through goal-directed attention (Hu et al., 2016). Thus, even if the perceptual filter prevents overload of VWM by allowing only relevant items to pass, internal control by the CE is necessary to maintain storage of those items (Hitch et al., 2018; Hitch et al., 2019; Hu et al., 2016).

Final considerations

The CE has been shown to play a role in maintaining information in the FoA through goal-directed attention (Hu et al., 2016). The present study corroborates previous hypotheses by Hu et al. (2016) and Allen et al. (2017) about the CE: this component does not appear to control the passage of targets and distractors through the perceptual filter, but has an active role in maintaining items in the FoA by controlling the allocation of attentional resources. This explains both the maintaining of targets and exclusion of distractors in visual working memory tasks. Hence, contrary to Chun et al. (2011), external and internal attention appear to be separate structures in working memory. This finding argues against the hypothesis by Emrich and Busseri (2015) that filtering depends on top-down attentional control. Individual differences associated with failure to select visual information may be due to difficulties in discriminating and allocating attention to targets.

The hypothesis that external information is selected automatically by the perceptual filter according to plausibility criteria has been investigated before (Allen et al., 2017; Hu et al., 2014; Hu et al., 2016; Hitch et al., 2018). However, the possibility of independence between the perceptual filter and the CE, understood as an internal resource the role of which is limited to processing internal representations in VWM, and the existence of sub-regions in VWM with higher attentional levels, needs to be further investigated. Future studies may manipulate the existence of distractors to investigate the effects of distractor presence in performance and sensitivity in distinct conditions of concurrent task and instruction. Another possibility is the presentation of lures (items not previously presented) in the response screen. This may help to distinguish between false alarms due to incorrect selection of distractors and those due to fragmentation of color-shape pairs stored in VWM.

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Recebido em: 21/07/2020
Reformulado em: 14/05/2021
Aprovado em: 30/08/2021

About the authors:

Francéia Veiga Liedtke is a Master and doctoral student in psychology by the Graduate Program in Psychology at the Federal University of Rio Grande do Sul - UFRGS (Porto Alegre, Rio Grande do Sul, Brazil) . Researcher at the Cognitive Neuropsychology Research Center (NEUROCOG). Orcid: 0000-0002-5252-0337.
ORCID: https://orcid.org/0000-0002-5252-0337
E-mail: franceia.liedtke@gmail.com

Juliana Burges Sbicigo is a Master and doctor in psychology by the Graduate Program in Psychology at the Federal University of Rio Grande do Sul - UFRGS (Porto Alegre, Rio Grande do Sul, Brazil). Professor of the undergraduate program in psychology of Factum College. Collaborating researcher at the Cognitive Neuropsychology Research Center (NEUROCOG).
ORCID: https://orcid.org/0000-0001-9600-3318
E-mail: julianasbicigo@gmail.com

Laura Tamborindeguy França is an Undergraduate psychology student at the Federal University of Rio Grande do Sul (Porto Alegre, Rio Grande do Sul, Brasil). Research assistant at the Cognitive Neuropsychology Research Center (NEUROCOG).
ORCID: https://orcid.org/0000-0001-5840-6335
E-mail: tfranca.laura@gmail.com

Ana Luiza Tonial is an Undergraduate psychology student at the Federal University of Rio Grande do Sul (Porto Alegre, Rio Grande do Sul, Brasil). Research assistant at the Cognitive Neuropsychology Research Center (NEUROCOG).
ORCID: https://orcid.org/0000-0002-8503-129X
E-mail: analuiza.tonial@hotmail.com

Alexandre de Pontes Nobre is a Master and Doctor in psychology by the Graduate Program in Psychology at the Federal University of Rio Grande do Sul - UFRGS (Porto Alegre, Rio Grande do Sul, Brazil) and by the Laboratory of Experimental Psychology at the University of Leuven - KU Leuven (Leuven, Belgium). Post-doctoral researcher at the Timing and Cognition Lab - Federal University of ABC (UFABC).
ORCID: https://orcid.org/0000-0002-1653-4467
E-mail: alpnobre@gmail.com

Jerusa Fumagalli de Salles is a Master and Doctor in developmental psychology. Associate Professor of the Institute of Psychology and the Graduate Program in Psychology at the Federal University of Rio Grande do Sul - UFRGS (Porto Alegre, Rio Grande do Sul, Brazil). Principal Investigator at the Cognitive Neuropsychology Research Center (NEUROCOG) and member of the Research Ethics Committee of the Institute of Psychology (UFRGS). Receives a research grant by the Brazilian National Council for Scientific and Technological Development (CNPq).
ORCID: https://orcid.org/0000-0003-0877-488x
E-mail: jerusafsalles@gmail.com

Contact:

Universidade Federal do Rio Grande do Sul, Instituto de Psicologia
Av. Ramiro Barcelos, 2600, sala 214
Instituto de Psicologia, Núcleo de Estudos em Neuropsicologia Cognitiva
Porto Alegre-RS, Brasil
CEP: 90040-060
Telefone: (51) 33085341