

Gender Differences in Visuospatial Working Memory

—Does Emotion Matter?

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Abstract

Sex-based differences in visuospatial working memory (VSWM) processing have been documented previously. However, there is a significant lack of empirical data on the gender-related effects on both cognitive load, and the emotional content of spatially-remembered objects in VSWM. In order to explore this issue, 50 young adults (25 males) voluntarily participated in performing a VSWM task with two different levels of cognitive load. Trials included 4 or 6 facial (happy, fearful and neutral faces), or non-facial, stimuli, presented sequentially at randomized spatial locations, and subjects were asked to reproduce the sequences in inverse order. Behavioral results showed that both males and females performed more accurately and faster when the sequences to be reproduced were shorter. In general, males performed significantly better than females, but particularly when reproducing longer sequences. Males and females were sensitive to the emotional content of the stimuli, as both genders achieved significantly more correct responses during trials with happy faces. Results suggest that gender-based differences on VSWM processing go beyond discriminating processes, and may involve dissimilarities in cognitive strategies, and/or underlying neural substrates.

Keywords: visuospatial working memory, gender, emotional faces, cognitive load

1. Introduction

As part of everyday social interaction, subjects must not only recognize faces in the environment, but also identify their emotional expressions and the spatial location in which they are seen, as this ability represents an adaptive advantage in terms of predicting future actions and adjusting one's behavior accordingly. There is sufficiently empirical evidence in this field to allow us to affirm that emotional faces are identified more accurately and quickly than other changing objects (Jenkins, Lavie, & Driver, 2005; Reinders, den Boer & Büchel, 2005; Ro, Russell, & Lavie, 2001).

When an emotional stimulus, particularly a facial one, is processed, several mechanisms converge to distinguish and contextualize it. Numerous studies have addressed the effects of affective stimuli on cognitive processes such as attention, memory and executive functions (Banich et al., 2009; Delplanque, Lavoie, Hot, Silvert, & Sequeira, 2006; Fenske & Eastwood, 2003; Lindström & Bohlin, 2012; Hoffstetter, Achaibou, & Vuilleumier, 2012; Pessoa, 2010; Pessoa, 2012; Pessoa, Padmala, Kenzerm, & Bauer, 2012; Phelps, 2006; Pourtois, Schettino, & Vuilleumier, in press). It is possible that the appearance of an emotional stimulus might interfere with the processing of other stimuli that appear in the temporal vicinity, basically due to the fact that stimuli with emotional content attract greater attentional resources because of their adaptive significance (Ledoux, 1996; Vuilleumier, Armony, Driver, & Dolan, 2001).

The effect of covert attention on spatial and temporal resolution may be enhanced by the emotional significance of a spatial cue. Upon comparing fearful versus neutral face cues, Bocanegra & Zeelenberg (2011) recently found that emotion increases the strength of a cue's attentional response. In addition, evidence seems to support

the finding that some facial expressions - such as a negative one - may enhance the attentional shifts due to eye-gaze direction (Pecchinenda, Pes, Ferlazzo, & Zoccolotti, 2008). In this context, it has been postulated that females have better overall face recognition than males, but only when facial stimuli are visually present for longer periods, probably by obtaining greater profits from encoding/re-encoding mechanisms (Weirich, Hoffmann, Meissner, Heinz, & Bengner, 2011). Indeed, evidence points towards the existence of cognitive and emotional processing differences between males and females.

In general, the gender-related differences include a wide range of processing skills. It has been shown that females recall better the appearance of others better than males (Mast & Hall, 2006) and score higher on tasks involving manipulation of phonological and semantic information, episodic and semantic memory, verbal learning, verbal analytical working memory (WM), object location memory, fine motor skills and perceptual speed, while males tend to score higher on tasks involving visuospatial working memory (VSWM), fluid reasoning, and positional reconstruction, or when spatiotemporal analyses are required (Duff & Hampson, 2001; Halpern, 1997; Kramer, Delis, Kaplan, O'Donnell, & Prifitera, 1997; Lejbak, Vrbancic, & Crossley, 2009; Maitlan, Herlitz, Nyberg, Bäckman, & Nilsson, 2004; Postma, Winkel, Tuiten, & van Honk, 1999; Ramos-Loyo & Sánchez-Loyo, 2011; Voyer, Postma, Brake, & Imperato-McGinley, 2007).

The literature has addressed numerous findings that support several brain anatomical, gender-related brain differences, such as males having a significantly larger left versus right planum temporale area, a difference that is not significant in females (Kulynych, Vladar, Jones, & Weinberger, 1994); the finding of a larger splenium in females versus a larger genu in males, which is one aspect of the gender-related differences in the dimensions of the corpus callosum (Dubb, Gur, Avants, & Gee, 2003); and hippocampal volumetric sex-differences (Maller, Réglade-Meslin, Anstey, & Sachdev, 2006), among some other distinctions. From a functional point of view, several studies have described gender-related differences in brain activation patterns when performing a variety of cognitive tasks, although performance in these tasks does not necessarily vary, and variability in performance may not be reflected in differences in brain activation (Bell, Willson, Wilman, Dave, & Silverstone, 2006; Grabner, Fink, Stipacek, Neuper, & Neubauer, 2004). Also, in the particular case of VSWM tasks, gender-related differences could be present in both behavioral performances –which tends to be better in males- and brain activation patterns (Schöning et al., 2007).

Despite the growing interest in the relationships between cognition and emotion, especially those that involve cognitive load, emotional content and operations in VSWM, there is a marked paucity of data on gender-related differences. In this area, Wraga and colleagues (2007) examined women's performance of a spatial reasoning task induced by positive and negative stereotypes using fMRI techniques. They found that females were somewhat sensitive to stereotyped messages that perhaps affect cognitive strategies and brain selectivity; whereas positive messages produced relatively more efficient neural strategies than negative ones, and revealing several differences in the resulting brain activation patterns. In a study using an n-back verbal WM task, Koch and colleagues (2007) evaluated the influence of negative emotions induced via olfactory stimulation, on brain activation patterns across gender. They found that while performing the WM task, negative emotions produced an extended activation pattern mainly involving the prefrontal and superior parietal regions in males, while females exhibited a stronger response in the amygdala and the orbitofrontal cortex, suggesting that different gender-specific neural mechanisms are triggered when emotional and cognitive processing interact.

With respect to WM's important role in the recognition, encoding and manipulation of task-related and concurrent distractor stimuli, the influence of WM load on attentional modulation and, consequently, how this influences WM performance while processing faces has been recurrently evaluated using different behavioral measures, along with imaging and electrophysiological techniques. Studies in this area have shown that increasing mnemonic demands lead to decrements in the magnitude of the activation in functional magnetic resonance imaging (fMRI), and in the latency and amplitude of the event-related N170 component (Gazzaley, 2011; Gazzaley, Cooney, McEvoy, Knight, & D'Esposito, 2005). In addition, late positive ERPs have been found to be sensitive to both WM load and the emotional content of the stimuli, where these two elements exert opposite effects on the attention paid to distracting stimuli (MacNamara, Ferri, & Hajcak, 2011), thus emphasizing the urgent need to clarify their functional interplay.

In this context, and in light of previous evidence, we hypothesized that cognitive load and facial emotional valence will induce gender-specific effects on VSWM-related performance. To this end, we designed an experiment in which the participants performed a VSWM task that involved two levels of difficulty and stimuli with different emotional valences.

2. Method

2.1 Subjects

A total of 50 healthy, university student volunteers [25 males: mean age= 25.19, standard deviation (SD) = 1.05, and 25 females: mean age= 24.32, SD= 0.89] participated in the experiment. Inclusion criteria were right-handedness and normal or corrected-to-normal vision. Exclusion criteria were a personal or family history of drug abuse or psychopathology, epilepsy, head injury and drug or alcohol use (within a 24 h prior to testing), all of which were assessed through clinical interviews. All subjects gave their written consent to participate in the study after they were fully instructed as to the experimental procedures. The study was previously approved by the ethics committee of the Neuroscience Institute.

2.2 Design and Procedure

A spatial WM experimental design was used, consisting in the sequential presentation of series of 4 or 6 stimuli. For both series, two different visual stimuli were used: facial (happy, fearful, neutral faces), or non-facial (squares). Facial stimuli consisted of 30 full-color, 16 ×13 cm photographs of Hispanic models (5 males, 5 females). These facial expressions had been categorized previously and correctly with a hit rate above 90% by a pool of 20 similar subjects in a previous pilot study, and subsequently used in other experiments. Neutral squares corresponded to the non-facial control condition and were built by randomizing the pixels of all the facial image stimuli. All stimuli were shown in different areas of a 21" touch-screen (SVGA monitor; refresh rate: 100 Hz) with a central white dot as the fixation. All facial stimuli in one trial had the same valence and unbeknownst to the participants. The screen area was divided by software into 2 rows and 3 columns to define 6 identical regions in which the stimuli could appear at random.

Participants were seated comfortably in a quiet, dimly-lit room, the screen being at a viewing distance of 60 cm. They were previously instructed and trained to reproduce the inverse order of the showed sequence, by pressing as quickly as possible the corresponding screen positions with their right index finger, as soon as the cue "RESPONSE" appeared in the center of the screen. Each trial begins with a central cross lasting for 1500 ms, then each stimulus, 4 or 6 according the type of series, was presented during 2000 ms with an inter-stimulus interval of 1500 ms. The command "RESPONSE" lasted 1500 ms and was followed by a screen-in-black period with maximum duration of 4000 ms while responses were submitted. If the response was completed before this time period, then the next trial was triggered automatically. Figure 1 illustrates the experimental flow chart.

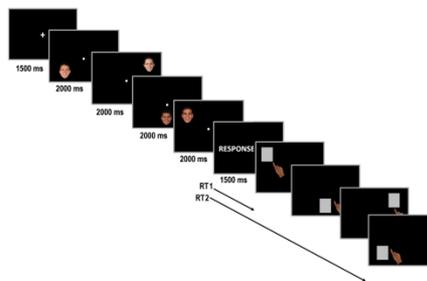


Figure 1. Experimental flow chart showing a 4-stimuli sequence trial

Each type of stimuli was used to assemble 30 trials for each sequence length (4 or 6 stimuli). Consequently, a total of 240 trials (120 per sequence length) were randomly divided into 4 blocks of 60 trials each. After each block, subjects were allowed a brief rest period. The presentation order of the blocks, the spatial location of the stimuli in each trial, and the presentation order of the trials in each block were all counterbalanced.

2.3 Behavioral Data Analysis

During task performance, the number of correct responses and reaction times were measured. Although a delayed-response experimental task was used, two response times were automatically measured per trial; the first response time (RT1) corresponded to the lapse between the visual appearance of the response warning and the instant in which the subject touched the screen for the first time. The second reaction time (RT2), corresponded to the total time elapsed between the response warning and the instant at which the subject completed the response (when the entire inverse sequence of each trial was reproduced on the touch screen).

A mixed-design three-factor repeated measures analyses of variance (RM-ANOVAs) were applied for behavioral responses [gender: male, female; cognitive load (short sequences: 4 elements, and long sequences: 6 elements) and type of stimuli (happy face, fearful face, neutral face, neutral square)]. Post-hoc Tukey's HSD tests were used to explore any trends in the differences found.

3. Results

The analysis showed that the number of correct responses was significantly higher in males than in females ($F_{1,48}=5.807$, $p<0.05$; $\eta^2_p=.108$). In general, the statistical analyses demonstrated that, regardless of the type of stimuli, the number of correct responses was higher for the shorter sequences ($F_{1,48}=232.3$, $p<0.001$; $\eta^2_p=.829$), which corresponded to a lower cognitive load level. In addition, the interaction between the factors of cognitive load and gender was statistically significant, demonstrating that males achieved a higher number of correct responses than females, but only when performing longer sequences ($F_{1,48}=4.7$, $p<0.05$; $\eta^2_p=.089$). Table 1 shows the number of correct responses in the two groups while processing the different types of stimuli.

Table 1. Mean averaged correct responses while performing the experimental task

Memory Load	Type of Stimulus	Correct Responses		
		Males Mean (SD)	Females Mean (SD)	Total Mean (SD)
4 stimuli	Happy Face	26.3 (2.4)	24.4 (3.8)	25.4 (3.3)
	Fearful Face	24.4 (4.2)	23.0 (3.9)	23.7 (4.1)
	Neutral Face	25.2 (4.6)	22.3 (4.1)	23.8 (4.5)
	Control	24.6 (4.6)	22.1 (4.5)	23.3 (4.7)
	<i>Mean (SD)</i>	25.1 (4.1)	22.9 (4.1)	
6 stimuli	Happy Face	20.9 (5.3)	16.0 (6.7)	18.5 (6.5)
	Fearful Face	19.3 (6.1)	15.8 (6.3)	17.5 (6.4)
	Neutral Face	19.3 (5.0)	16.2 (6.4)	17.7 (5.9)
	Control	19.1 (5.8)	14.4 (6.2)	16.7 (6.4)
	<i>Mean (SD)</i>	19.6 (5.5)	15.6 (6.4)	

SD: standard deviation

In addition, there was a significant effect for the type of the stimuli ($F_{3,144}=12.8$, $p<0.001$; $\eta^2_p=.312$). Pairwise comparisons showed that correct responses were higher when trials contained happy faces, in comparison to those in which fearful ($p<0.01$), neutral faces ($p<0.01$), or control stimuli ($p<0.01$) appeared.

First reaction time (RT1)

A gender-related effect was found, where males showed significantly lower reaction times for the correct responses than females ($F_{1,48}=9.850$, $p<0.01$; $\eta^2_p=.170$). Also, there was a significant effect of the length of the sequence ($F_{1,48}=94.320$, $p<0.001$; $\eta^2_p=.663$), denoting that in addition to the type of stimuli, longer sequences were also associated with longer reaction times. Table 2 shows the first response times (RT1) for the two groups while processing the different types of stimuli.

Table 2. First response times (RT1) in the two groups

Memory Load	Type of Stimulus	Response Times (RT1)		
		Males Mean (SD)	Females Mean (SD)	Total Mean (SD)
4 stimuli	Happy Face	922.6 (206.2)	1092.2 (161.0)	1007.4 (202.1)
	Fearful Face	911.9 (178.3)	1093.9 (178.9)	1002.9 (199.2)
	Neutral Face	902.2 (179.8)	1083.8 (172.8)	993.0 (197.2)
	Control	935.6 (179.4)	1096.3 (169.6)	1015.9 (190.9)
	Mean (SD)	918.1 (183.9)	1091.6 (168.2)	
6 stimuli	Happy Face	1075.0 (187.8)	1207.5 (199.3)	1141.3(203.0)
	Fearful Face	1092.6 (186.8)	1223.9 (190.0)	1158.3(197.9)
	Neutral Face	1084.2 (194.7)	1227.8 (200.6)	1156.0(208.6)
	Control	1086.1 (187.2)	1212.9 (190.5)	1149.5(197.6)
	Mean (SD)	1084.5(186.4)	1218.1 (192.4)	

SD: standard deviation

Global Reaction Time (RT2)

As it occurred in RT1, the statistical analysis demonstrated a gender-related effect in RT2, in which males exhibited shorter global reaction times as compared to females ($F_{1,48}=6.427$, $p<0.05$; $\eta^2_p=.118$). Also, the length of the sequence significantly induced prolonged response times ($F_{1,48}=1093.8$, $p<0.001$; $\eta^2_p=.958$). Table 3 shows the results of global response times (RT2) for the two groups while processing the different types of stimuli.

Table 3. Global response times (RT2) in the two groups

Memory Load	Type of Stimulus	Response Times (RT2)		
		Males Mean (SD)	Females Mean (SD)	Total Mean (SD)
4 stimuli	Happy Face	2574.7(374.8)	2786.0(382.5)	2680.3 (389.7)
	Fearful Face	2583.4(349.2)	2856.6(360.6)	2719.9 (377.4)
	Neutral Face	2547.8(374.0)	2825.6(393.7)	2686.7 (405.1)
	Control	2572.8(366.6)	2779.1(368.3)	2675.9 (378.3)
	Mean (SD)	2569.7(360.9)	2811.8(372.1)	
6 stimuli	Happy Face	3354.8 (505.2)	3693.1 (404.2)	3523.9 (483.9)
	Fearful Face	3343.6 (481.2)	3692.8 (410.5)	3518.2 (476.5)
	Neutral Face	3358.1 (511.6)	3705.0 (428.6)	3531.6 (498.9)
	Control	3402.3 (477.2)	3693.7 (426.1)	3548.0 (471.3)
	Mean (SD)	3364.7 (487.0)	3696.2 (411.1)	

SD: standard deviation

4. Discussion

In general, the sequence-length effect reflected the dissimilar WM load levels required to fulfill the experimental task, which involved different degrees of task difficulty. This result matches the previous work on this topic (Cusack, Mitchell, & Duncan, 2010; Galy, Cariou & Mélan, 2011; Nagel et al., 2011; Tregellas, Davalos & Rojas, 2006), which has shown that these results are highly predictable from a neuro-cognitive perspective (see

Schneider, 1999 for a review).

Based on empirical evidence showing that males usually perform better on spatial working memory tasks (Duff & Hampson, 2001; Lejbak, Vrbancic, & Crossley, 2009; Ramos-Loyo & Sanchez-Loyo, 2011; Voyer, Postma, Brake, & Imperato-McGinley, 2007) one of the initial hypotheses of the present study was that regardless the length of the sequence, males would achieve a higher number of correct responses than females. Although this assumption was fulfilled in general, more detailed assessment of the experimental results showed that males did indeed perform significantly better than females, but only while reproducing longer sequences.

On the topic of empirical evidence derived from spatial working memory task experiments, gender differences seem to apply only to selective dimensions of spatial functioning. Thus, when visuo-spatial ability is analyzed, it may be important to distinguish different perceptually based processes and a variety of kinds of higher level, more demanding functions (Voyer & Bryden, 1990). Also, more active tasks such as those requiring manipulation of mental images and/or mental rotation have exhibited the most important differences favoring males, while the performance of passive tasks (e.g. loading spatial perception) tend to decrease these differences (see Voyer, Voyer, & Bryden, 1995; and Voyer et al., 2007 for reviews). Therefore, current gender-related behavioral differences on trials with higher working memory load might conceivably be explained as reflecting sex-related differences in the activation of specific correlated neural networks. In fact, the existence of dynamic changes in brain functional connectivity proposed as task-adaptive processes triggered by increasing working memory load demands which affect, basically, the frontal-executive and occipitoparietal-perceptual cortices (Brookes et al., 2011; Cocchi, et al., 2011) seem to support the explanation of these data. In addition, gender-related differences in the brain activation patterns elicited by the performance of spatial working memory tasks strengthen the aforementioned assumption (Schöning et al., 2007).

Even though the responses were delayed in each trial until a warning command appeared in the screen, there were significant gender-related differences in the duration of both averaged response times measured (delay to the beginning of the motor response -RT1-, and the total amount elapsed until the responses were completed -RT2). Thus, males not only initiated their responses significantly earlier than females, but they also completed them faster. This result matches previous empirical data showing that the speed of motor performance is significantly better in males across the age groups (Karlins, & Helmut, 1965; Laszlo, Bairstow, Ward, & Bancroft, 1980; Moreno-Briseño, Díaz, Campos-Romo, & Fernandez-Ruiz, 2010; Jiménez-Jiménez et al., 2011).

This study also found significant differences in behavioral responses related to stimuli type, as performance on trials involving happy faces was significantly better than that achieved while processing sequences of fearful faces, neutral faces or visual noise. In this context, the facial distracting effect could be elucidated in light of the load theory of selective attention (Lavie, Hirst, de Fockert & Viding, 2004), which assumes that higher cognitive demands may trigger perceptual adaptation mechanisms that seek to reduce distractor perception. Indeed, there is sufficient evidence to assume that when visual attention is taxed by perceptually-demanding tasks, irrelevant visual distractors are strongly suppressed (Lavie, et al., 2004; Schwartz et al., 2005; Yi, Woodman, Widders, Marois, & Chun, 2004). Thus, while one might expect that current behavioral differences due to stimuli type would diminish while processing longer sequences, they actually increased.

This is not surprising when we take into account the fact that the type of WM load manipulated could be critical in determining the consequences of distractor processing (Kim, Kim, & Chun, 2005; Park, Kim, & Chun, 2007). In the present study, the modality of the WM load did not completely overlap with that of the visual distractors, thus their perceptual suppression was not facilitated. In addition, stimuli presentation lasted sufficient time to permit further perceptual analysis.

Due to dissimilarities observed while processing happy *versus* other facial emotional contents, these results must be explained on the basis of an emotion-related facial processing effect, as the simple appearance of facial stimuli does not account for the differences found. In fact, previous findings on a happiness detection advantage relative to both angry (Becker et al., 2011, 2012; Juth et al. 2005) and sad (Srivastava & Srinivasan, 2010) faces, could justify the present results. These findings have allowed the authors to postulate that the facial expression of happiness has evolved to be more visually discriminable, probably because its communicative intent is less ambiguous than other facial expressions (Becker et al., 2011).

As stated above, several previous studies have demonstrated that facial emotional features can be disruptive to goal-oriented behavior (Ellis & Ashbrook, 1988) while influencing working memory task responses (Fenske & Eastwood, 2003; Mogg & Bradley, 1999), particularly during lower memory load demands, in which spare capacity spills over, resulting in the analysis of task-irrelevant, distracting stimuli (González-Garrido, Ramos-Loyo, Gómez-Velázquez, Alvelais-Alarcón, & de la Serna Tuya, 2007).

It has been reported that activation of the intraparietal sulcus reflects short-term visual memory performance across varying memory loads (Sheremata, Bettencourt & Somers, 2010). In addition, separate memory systems involving parahippocampal gyri, the inferior parietal gyrus, the anterior cingulate gyrus and the right caudate nucleus all seem to participate when spatial information is stored (Janzen & Weststeijn, 2007), or to depict a right frontoparietal network when object-based processing is carried out (Galati et al., 2000). In view of the fact that recognizing neutral faces elicits activation of the fusiform gyri (Jehna et al., 2011), and of increasing evidence from other neuroimaging studies indicating different neural correlates for memory load and facial emotional processing (Jackson, Wolf, Johnston, Raymond, & Linden, 2008), one could hypothesize that such extensive neural activation –based on stimulus and task characteristics– might temporarily improve cognitive processing capabilities in certain circumstances (i.e., happy faces). Evidence from several fMRI studies using dual-task designs (de Fockert, Rees, Frith, & Lavie, 2001; Rissman, Gazzaley, & D'Esposito, 2009) has shown that top-down signals related to working memory may amplify neuronal responses associated with a perceptual task while suppressing task-irrelevant neural responses, thus supporting the above assumption.

However, no significant gender-related differences were found between the responses emitted on the different types of the stimuli. This could well be due to the fact that regardless of the emotional content that the faces might have shown, the content was completely irrelevant to achieving the task's main goal. In other words, even though there are very well known differences between males and females in terms of visual perception, processing speed and object location memory among several other cognitive functions, discarding an irrelevant stimulus from the currently performed task could rely on more general unspecific mechanisms that are less sensitive to sexual processing differences. Alternatively, the lack of gender-related differences across different emotional stimuli content in the present experiment could be explained as a result of a habituation effect, due to the repeated exposure to the same emotional expression in each trial, which might attenuate possible gender differences, while maintaining the disruptive effect on behavioral responses under higher cognitive load conditions. The habituation of attentional networks during cognitive (Huber, 2008; Yamaguchi, Hale, D'Esposito, & Knight, 2004) and emotional processing has also been reported previously (Feinstein, Goldin, Stein, Brown, & Paulus, 2002).

In conclusion, the present results seem to demonstrate that there are marked gender-based differences in brain function that extend beyond the processing of simple visual or spatial WM information, to more complex discriminating processes in which the underlying neural substrates could possibly overlap and differ along with gender and perhaps several other variables. The present results emphasize the need for further studies to better delineate the nature of the differences found.

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