

Female advantage in visual working memory capacity for familiar shapes but not for abstract symbols

Adam Chuderski

Institute of Philosophy, Jagiellonian University in Krakow
Adam.Chuderski at uj.edu.pl

Jan Jastrzębski

Institute of Psychology, Jagiellonian University in Krakow
Jastrz.Jan at gmail.com

Abstract

Both behavioral studies and the neurophysiological data modelling suggested female advantage in memory for objects, however, most research pertained to long-term memory, whereas data from visual working memory (VWM) are scanty. In a large sample of 2044 people, the number of objects supposedly encoded in VWM was measured during the change detection task. The stimuli were either relatively familiar geometric shapes or less familiar Greek symbols. Controlling for the general ability level, a small but significant advantage for memorizing shapes in VWM was found in females over males, but no effect was observed for memorizing abstract symbols. The present results support neuroimaging models of human cognitive architecture, suggesting that female VWM relies on a more complex network of domain-specific brain modules, as compared to males. Consequently, formal models of VWM and related cognitive processes should account for sex and material type.

Keywords: visual working memory, sex differences, change detection task, neural architecture of memory

Introduction

Notable sex differences are observed in human memory, especially in long-term memory (LTM) and episodic memory (Halpern, 2013; Kimura, 1999). Research suggested that female brains are more effective in encoding and retrieving information pertaining to objects, episodes, faces, and verbal material, whereas males seem to better memorize spatial information (for reviews see Cahill, 2006; Herlitz & Rehnman, 2008). However, a relatively smaller number of studies were devoted to sex differences in working memory (WM), making this topic worth of closer examination.

WM is defined as a key neurocognitive mechanism responsible for active maintenance, effective updating, and controlled retrieval of task-relevant information during short periods of time (Cowan, 2001). At the same time, WM is believed to block task-irrelevant and distracting information (Kane & Engle, 2002). WM operation relies on short-term memory (STM), but most likely also involves memory processes beyond the sheer passive storage in STM. The key feature of WM is its limited capacity comprising the simultaneous representation of only several “chunks of information,” being objects, their features, and their

bindings. Given that WM is a key construct in psychology as well as a strong predictor of complex cognitive abilities, such as problem solving, fluid reasoning, and education (Kane, Hambrick, & Conway, 2005), vast research has been devoted to the neurocognitive underpinnings of WM. Establishing whether sex differences, commonly observed in other types of memory, do exist also in the case of WM performance, may contribute to our understanding of WM mechanisms. Moreover, if potential sex differences in WM are driven by the type of to-be-memorized content, in either a similar or a different way, in comparison to the content effects found for the other memory systems, such an observation may provide additional evidence for theoretical models that assume either close links between WM and LTM (Crowder, 1993; Nairne, 2002; Neath & Suprenant, 2003) or their relative separateness (e.g., Cowan, 2001; Kane & Engle, 2002; Vogel, Woodman, & Luck, 2001). The data can also guide design of the future studies on WM.

Sex differences in working memory

Early studies reported sex differences in WM that matched those found for LTM, with verbal tasks such as the reading span favoring females (e.g., Cochran & Davis, 1987), whereas spatial tasks such as the Corsi blocks favoring males (e.g., Grossi, Matarese, & Orsini, 1980). However, later studies reported differences that either were negligible, or highly variable from task to task (e.g., Duff & Hampson, 2001; Lejbak, Crossley, & Vrbancic, 2011; Postma, Jager, Kessels, Koppeschaar, & van Honk, 2004; Reed, Gallagher, Sullivan, Callicott, & Green, 2017; Robert & Savoie, 2006; for meta-analyses see Halpern, 2013; Voyer, Postma, Brake, & Imperato-McGinley, 2007; Voyer, Voyer, & Saint-Aubin, 2017; Wang & Carr, 2014).

Crucially, Speck et al. (2000) suggested that most of these cognitive studies were underpowered to detect robust sex differences in WM, whereas functional brain connectivity patterns differentiating females and males may be more informative than comparing WM capacity between females and males. Indeed, such patterns have been found (Filippi et al., 2013; Grabowski, Damasio, Eichhorn, & Tranel, 2003; Piefke et al., 2005). A comprehensive meta-analysis of 44

neuroimaging papers that studied males and another 15 that studies females, which used activation likelihood estimation (ALE) method, identified the brain regions most likely associated with sex differences. It showed that besides large overlapping structures in the frontal and parietal cortices, which are commonly attributed to WM, the female performance seems to depend also on additional prefrontal sites as well as hippocampus and anterior cingulate, whereas the male performance relies on additional parietal sites as well as insula (Hill, Laird, & Robinson, 2014).

However, it is still interesting to see how the observed sex differences in the brain activations might translate into behavioral differences in coping with tasks tapping WM. Only, a larger power is most likely needed to detect such behavioral consequences of neural differences. The present study aimed to investigate sex differences in visual working memory (VWM) using the varied types of to-be-memorized content. On the basis of previous research on sex differences in LTM, as well as interpreting the Hill et al.'s findings, it was assumed that the involvement of hippocampal regions in female WM may result in a better encoding of more concrete and familiar objects by females, as compared to males, because neurons in and around hippocampus are known to encode episodic information that can be linked to existing memory traces (see Eichenbaum, Yonelinas, & Ranganath, 2007; Wixted et al., 2014). The involvement in male WM of parietal and insular regions, commonly associated with awareness and attention (see Cowan et al., 2011; Eckert et al., 2009), can in turn yield the male advantage in encoding of less concrete and unfamiliar objects, which cannot be easily memorized using episodic and semantic traces, and thus require increased attentional effort. Indeed, some studies on episodic memory suggested the female advantage in recall and recognition of concrete pictures (Herlitz, Airaksinen, & Nordström, 1999) and familiar odors (Lehrner, 1993), but no advantage for more abstract images (ink blots and snow crystals; Goldstein & Chance, 1970) and unfamiliar odors (Öberg et al., 2002). Unfortunately, such a prediction has never been tested with regard to WM nor in large samples.

The present study analyzed data of 2044 people, collected over several published studies, conducted in the authors' laboratory between year 2007 and 2018. All these studies assessed VWM capacity using a simple recognition paradigm, called the change detection task, with stimuli being either geometric shapes or Greek symbols. The systematic use of the shape and the symbol variant of the change detection task gave an unique opportunity to check the sex \times material interaction in a sample size never examined to date, which might allow to overpass the Speck et al. objections regarding the behavioral studies of sex differences in WM. In line with Hill et al. (2014), the female advantage in VWM capacity for more concrete, more familiar geometric figures was expected, as such figures could be encoded via episodic/semantic traces in and around

hippocampus, which was a brain structure identified as a more specific to females. The male advantage in VWM capacity for more abstract, more unfamiliar Greek symbols was predicted, as such symbols could not be easily associated with episodic/semantic information, and might require increased attentional effort supported by the parietal sites and insula, found to be more active in males. Although the classification of shapes as more concrete, while Greek symbols as more abstract is not univocal (see Discussion), these two kinds of material were clearly different, and the examination of sex \times material interaction was worthwhile.

The study

Participants

The total sample encompassed 1310 females (aged 17 to 46 years, $M = 23.2$, $SD = 4.6$) and 734 males (aged 18 to 46 years, $M = 23.7$, $SD = 4.7$). All participants were recruited from general population via internet adverts, in a Central-European city. The prevalence of females in the sample unfortunately resulted from the robust tendency for female enrolment in the psychological study recruitment. All participants signed a written consent to participate, were screened for normal or corrected-to-normal vision and no history of neurological problems, and were informed that they could stop the experiment and leave the lab at will. All data were anonymized. All other procedural aspects of the study conformed to the WMA's Declaration of Helsinki.

Materials

The stimuli in each trial of the symbol variant of the change-detection task were randomly drawn from the set of 16 small Greek letters (α , β , δ , θ , λ , μ , π , etc.), whereas in the shape variant they were drawn from the set of 16 simple shapes (circle, square, rhombus, etc.). Each stimulus was approximately 2×2 cm in size and was presented in black on a grey background. Each variant included either 60 or 90 trials, depending on a study (preceded by several training trials). Each trial consisted of a virtual, 4×4 array filled with several stimuli (see Fig. 1). From four to nine stimuli were used across studies. The array was visible between 1 s and 4 s (depending on set size), and was followed by a 1-s black square mask. On random, either the second array was identical to the first or both differed by exactly one item at one location. Either the new or random item, respectively, was highlighted by a square border. The task was to press one of two response keys (Z, M) depending on whether the highlighted item differed or not. The order of task variants was random between the studies, and they were preceded and followed by other tasks. The task score was the estimated average number of objects that were effectively maintained in VWM (k ; Rouder et al., 2011), calculated as the participant's difference between the proportion of correct responses for arrays with the item change and the proportion of incorrect responses for unchanged arrays, multiplied by

the set size. For example, if in a six-object condition 80% correct was scored in the former trials, and 70% correct was scored in the latter trials, formula yielded $k = 6 \times (.80 - .30) = 3$ objects supposedly maintained in VWM. Thus, the k value is relatively insensitive to the actual set size.

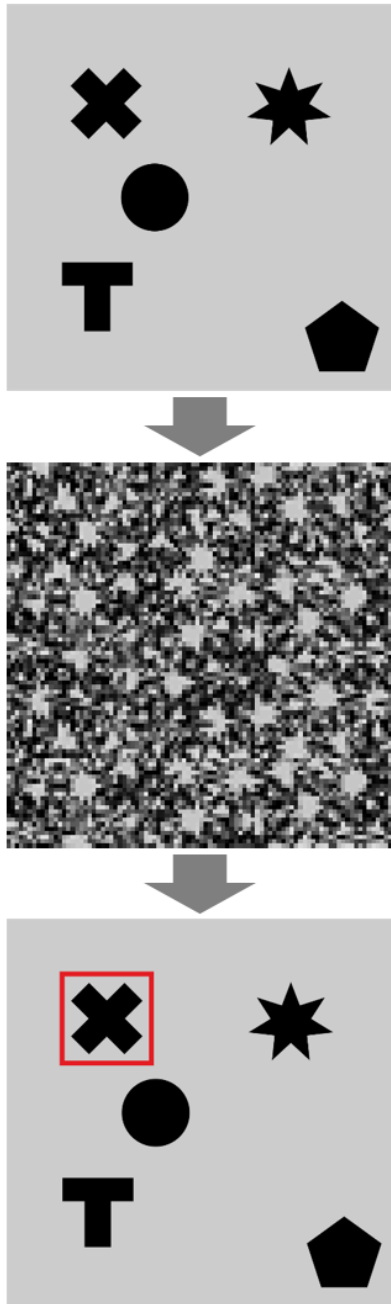


Fig. 1: Example stimuli and the sequence of events in the change detection task used in the study. The familiar shapes condition is shown; in the abstract symbols condition the task was identical except for Greek symbols were displayed. The “no-change” trial is shown; the “change trial was identical except for the shape (or symbol) surrounded by the rim in the bottom screen differed from the respective shape (or symbol) in the top screen.

As a short presentation time (2.5 s on average) and the graphical nature of stimuli practically eliminated their verbalization, it was assumed that the main difference between the tasks pertained to the concreteness and familiarity of stimuli, predicted to be larger for geometric shapes that commonly appear in the environment, whereas expected to be smaller for foreign Greek symbols that are not taught in schools and are rarely encountered in daily life and media in Poland, where the studies were held.

Additionally, general fluid intelligence (gf) was screened with two reasoning tests, Raven’s APM (Raven et al., 1983) and (depending on a study) either Figural analogies (Chuderski & Nęcka, 2012) or Culture Fair Test Version 3 (Cattell & Cattell, 1961). The test results were converted to Z scores, separately for each study, and then averaged to yield the gf factor value. As VWM capacity strongly correlates with fluid intelligence (see Kane et al., 2005), this gf factor was used as a covariate in comparisons between females’ and males’ VWM scores, in order to make sure that any sex difference in fluid intelligence does not account for the expected sex differences in VWM.

Results

Males displayed the mean gf value of 0.047 ($SD = 0.960$), whereas females scored $gf = -0.019$ ($SD = 0.883$), and this difference was not statistically significant, $t(2042) = 1.59$, $p = .112$. Fig. 2 presents the female and male distribution of k values, separately for each material variant. All four distributions were normal, and yielded comparable standard deviations both for the shape variant, $SD_{\text{female}} = 1.49$, $SD_{\text{male}} = 1.52$, and the symbol variant, $SD_{\text{female}} = 1.49$, $SD_{\text{male}} = 1.52$. Visual inspection of Fig. 2 suggests that in the shape variant the female distribution was shifted right, relative to the male distribution, while in the symbol variant the distributions closely matched.

To formally test this observation, the k values were submitted to ANCOVA, with sex and material as two factors, and the gf factor as a covariate. Fig. 2 shows the respective means and 95% CIs. The shape variant yielded a comparable performance ($k = 3.05$) to the symbol variant ($k = 2.98$), $F(1, 4080) = 2.17$, $p = .141$, suggesting that overall both materials were equally demanding. The key analysis pertained to sex differences. There was a marginal effect of sex ($k_{\text{female}} = 3.04$, $k_{\text{male}} = 2.99$), $F(1, 4080) = 4.09$, $p = .043$, but the sex effect was qualified by its significant interaction with material, $F(1, 4080) = 8.15$, $p = .004$, $\eta^2 = .002$. In the shape variant, females performed significantly better than males ($\Delta k = 0.18$), $F(1, 4080) = 11.94$, $p = .0005$, $d = .20$, but no significant sex difference was noted for the symbol variant, ($\Delta k = -0.08$), $F(1, 4080) = 0.34$, $p = .559$. For females, the difference between variants was statistically significant in favor of the shape variant ($\Delta k = 0.20$), $F(1, 4080) = 8.15$, $p = .004$, Cohen’s $d = .13$, while for males there was no significant difference between the two variants ($\Delta k = -0.06$), $F(1, 4080) = 0.75$, $p = .385$.

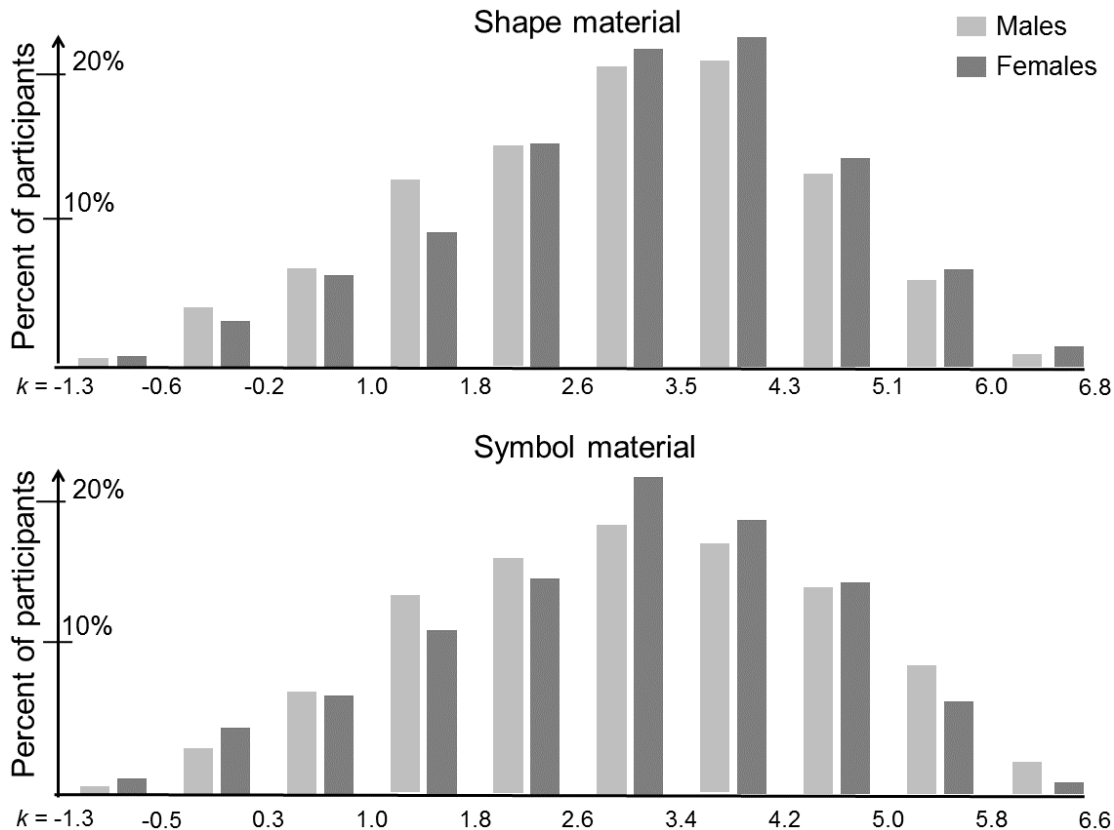


Figure 2: The distribution of k values for females and males.

The above analysis was also run without gf as a covariate, using rmANOVA with sex as a between-subjects factor and material as a within-subjects factor. The effect of sex was no longer statistically significant, $F(1, 2042) = 0.73, p = .392$, but the interaction of this factor with material was fully comparable with the preceding analysis, $F(1, 2042) = 15.21, p = .0001, \eta^2 = .001$. Female advantage over males for the shape material was highly significant, $F(1, 2042) = 7.03, p = .008$, while for the symbol material again there was no significant sex difference, $F(1, 2042) = 1.35, p = .246$. The shape material, as compared to symbols, yielded larger k values in females, $F(1, 2042) = 23.67, p < .0001$, but no significant difference related to material was noted for males, $F(1, 2042) = 1.51, p = .215$.

In order to validate the null sex effect for the symbol material, ANCOVA was applied to another sample of 1486 people (aged 15 to 46, $M = 22.76, SD = 4.06, N_{\text{female}} = 938$), who performed only the symbol variant. They were also screened with two reasoning tests, which this time more visibly differentiated the two sexes, $t(1484) = 2.41, p = .016$ ($gf_{\text{female}} = -0.052, gf_{\text{male}} = 0.075, SD_{\text{female}} = 0.89, SD_{\text{male}} = 0.96$). However, also in this sample ANCOVA showed no significant difference for the symbol material between females ($k = 3.21$) and males ($k = 3.31$), $F(1, 1483) = 0.36, p = .546$. This difference was not significant even when the two samples were combined, $F(1, 2527) = 0.74, p = .389$.

Finally, no differences in correlation between the k and gf values was observed. For the shape material, the respective correlation coefficient was numerically the same both in the female and the male sub-sample, $r = .40, p < .0001$. It was quite comparable to the respective coefficients for the symbol material, $r_{\text{female}} = .37, r_{\text{male}} = .34, ps < .0001$.

Discussion

Neuroimaging data (Hill et al., 2014) suggested that WM tasks, besides the common prefrontal and parietal sites, activate additional prefrontal and hippocampal regions in the female brains, whereas additional parietal and insular regions in the male brains. The present analysis of the large set of scores in the change detection task tested behavioral consequences of this female/male neuronal specificity. Results indicated that one potential consequence of the sex differences in brain networks underlying WM is the female advantage in VWM capacity for more concrete, more familiar stimuli (possibly encoded by episodic/semantic traces in and around hippocampus), which is absent for more abstract, less familiar stimuli (possibly requiring more attention rooted in parietal sites and insula). As the sample size was particularly large as for the WM research, the data were gf -corrected, and the female advantage was specific for one type of material but not for the other, the reported effect very likely reflects factual difference between the sexes, and not just a sample-dependent variation.

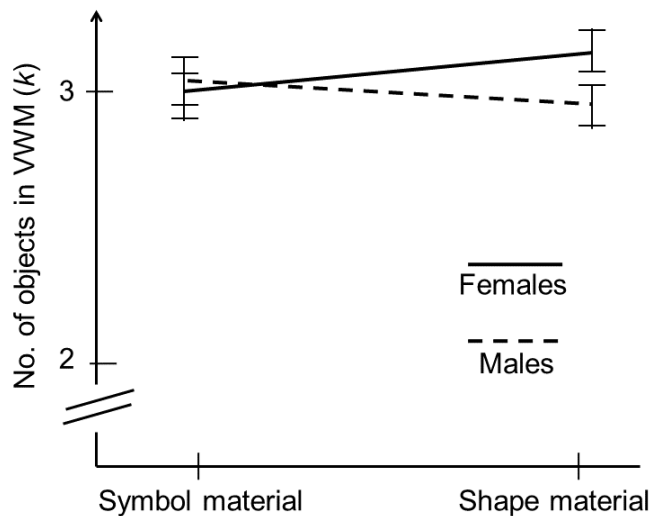


Fig. 3: Mean k values for females and males, depending on material type. Bars = 95% confidence intervals.

However, the female advantage for the shape material was quite small ($\Delta k = .18$). As the average VWM capacity was about three objects, females surpassed males by around 6%. This amount is in line with the Hill et al. conclusion that the lion's share of WM processing in both females and males relies on the shared prefrontal and parietal regions. However, given a strongly limited nature of WM, even such 6% can count, and females' potential reliance on specialized memory mechanisms may boost memory performance when a memorized content is compatible with those mechanisms. The present effect of stimulus familiarity was also much smaller than differences in episodic and semantic memory that were reported in the literature (see Cahill, 2006; Halpern, 2013; Herlitz & Rehnman, 2008; Kimura, 1999).

In contrast, the initially predicted male advantage for the symbol material was not observed in the data. After consideration, it seems that this prediction might be premature. Male advantage has been reported primarily for spatial material (Cahill, 2006; Grossi et al., 1980; Herlitz & Rehnman, 2008; Lewin, Wolgers, & Herlitz, 2001; Voyer et al., 2017), whereas more abstract material in fact did not differentiate the sexes (Goldstein & Chance, 1970). A more plausible interpretation of the null effect for the abstract symbols is that the additional involvement of attention might just have eliminated the female advantage rooted in more effective specialized memory processes (Herlitz & Rehnman, 2008; Voyer et al., 2007), but its contribution was too weak to yield the performance advantage of males.

One limitation of the study was the material used. Using other material than geometric shapes and Greek symbols would broaden the scope of conclusions that could be drawn from the present study. However, this study relied on the already existing data set, which included only two types of material. Moreover, the assumption that only shapes were familiar to participants, and could be encoded in episodic memory, but the symbols could not, might be objected.

Obviously, Greek symbols are also a kind of shapes, and at least some of them (e.g., α , β) could be verbalized, what helps in episodic encoding. So, we agree with all those objections. However, we think that the attenuated variant of this assumption, stating that shapes are *relatively* more familiar than Greek symbols (at least in the population with minimal exposure to Greek alphabet), and can be *relatively* more easily encoded in episodic memory, can be valid.

Summary

The present analysis of the existing large-size data set revealed the statistically significant difference between female and male WM performance on the relatively familiar, graphical material (but not on the more abstract material), which, on the one hand, most likely would be overlooked by a single study, whereas, on the other hand, might not be easily identifiable in meta-analyses of multiple studies applying diverse and not easily comparable methods. Overall, this kind of neuroimaging-driven psychometric analyses of sex differences in memory performance can shed light on the mechanisms underlying various memory systems as well as human cognitive architecture. The present study suggests that formal models of memory and related processes should account for sex and material type.

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