4-1-2010

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SEX DIFFERENCES IN VERBAL AND VISUAL-SPATIAL TASKS UNDER DIFFERENT HEMISPHERIC VISUAL-FIELD PRESENTATION CONDITIONS[1]

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[1] This study was funded by a Bond University Vice-Chancellor's research grant awarded to Gregory J. Boyle, PhD., DSc., Department of Psychology, Bond University, Gold Coast, Queensland 4229, Australia. Address correspondence to Gregory J. Boyle, or e-mail (gregb@bond.edu.au).

Summary

This paper reports sex differences in cognitive task performance that emerged when 39 Australian university undergraduates (19 men; 20 women) were asked to solve verbal (lexical) and visual-spatial cognitive matching tasks which varied in difficulty and visual field of presentation. Sex significantly interacted with task type, task difficulty, laterality, and changes in performance across trials. The results revealed that the significant individual-differences' variable of sex does not always emerge as a significant main effect, but instead in terms of significant interactions with other variables manipulated experimentally. Our results show that sex differences must be taken into account when conducting experiments into human cognitive-task performance.

Sex differences in human cognitive functioning is a controversial topic, especially when it refers to differences pertaining to broadly conceived intellectual functions like general intelligence. Sex differences observed in such intelligence studies (e.g., Jackson & Rushton, 2006; but see Halpern & LaMay, 2000, for a review) are, if found, relatively small when compared with differences in more defined cognitive functions. Tasks that tap cognitive functions can be examined in experiments wherein variables such as task type (e.g., verbal vs visual-spatial), task difficulty, and brain laterality are manipulated systematically, and the effects of these manipulations observed on dependent variables such as reaction time (RT), accuracy of response, or psychophysiological variables such as skin resistance level (SRL), or heart rate (HR) (cf. Neumann, Lipp, & Siddle, 1997; Lipp, Neumann, & McHugh, 2003; Neumann, Fitzgerald, Furedy, & Boyle, 2007; Furedy, 2008; Geus & Neumann, 2008).

The type of cognitive task seems to be a particularly important variable in that it can interact with the variable of sex (cf. Pryzgoda & Chrisler, 2000). For example, the group advantage for women over men on some verbal tasks tends to be reversed for certain visual-spatial and mathematical tasks (see Halpern & Wright, 1996; Halpern, 2000, 2004; Kimura, 1999, 2004). Weiss, Kemmler, Deisenhammer, Fleishhacker, and Delazer (2003) tried to evaluate the magnitude of sex differences in verbal and visual-spatial functions in 97 women and men. They found that women generally tended to outperform men on most spatial verbal tests whereas men tended to outperfom women on visual-spatial tasks. Nevertheless, the effect sizes were generally small, suggesting that the variance within male and female scores is much greater than the variance between groups.

Few researchers have directly compared verbal and visual-spatial tasks in the same experiment when examining sex differences. In research that has made such comparisons, it is apparent that the tasks of verbal and visual-spatial ability have differed not only in the nature of the stimuli used, but also in other qualitative features (cf. Jesus Zayas, 1989). These features can include the mode of stimulus presentation (visual vs auditory), relative emphasis on speed vs accuracy of response, time limits, and instructional set. Any one or a combination of these factors can influence the magnitude of observed sex differences by influencing performance factors. For instance, imposing time limits tends to give men an advantage over women in general for some tasks (Goldstein, Haldane, & Mitchell, 1990). Men also generally respond more rapidly on a simple response time task (Silverman, 2006). On the other hand, it has been suggested that women generally prefer to perform tasks more slowly and carefully than men (Maccoby & Jacklin, 1974). Clearly, it is important that performance factors such as the type and nature of response are kept constant in empirical research that examines how sex interacts with type of cognitive task (cf. Pöğün, 2001).

Algan, Furedy, Demirgören, Vincent, and Pöğün (1997) developed both a verbal and a visual-spatial matching task that could be presented under similar task requirements. The tasks also varied the visual-field of presentation. The participants were required to view briefly presented visual displays containing letters (verbal task)--(cf. Boyle, 1975, for information about tachistoscopically presented letter arrays) or graphics (visual-spatial task) and to make a speeded response to indicate whether a match or mismatch in the display was present (see F_1 for an adaptation of the display used in the present experiment). In the Algan, et al. study, the expected female advantage (shorter mean RTs) emerged on a verbal matching task, but no significant sex differences were found on a visual-spatial matching task (cf. Loring-Meier & Halpern, 1999; Deary, Der, & Ford, 2001; Colom, Contreras, Arend, Garcia Leal, & Santacreu, 2004; Camarata & Woodcock, 2006). Performance was also expected to improve over task repetition, yet men actually showed a deterioration of performance as reflected in longer RTs. The authors interpreted this sex difference as reflecting the operation of various cognitive or noncognitive influences on matching task performance.

This paper reports a pilot study with adult (Australian) participants using modifications of the Algan, et al. (1997) verbal and visual-spatial matching tasks. One aim was to test whether the Turkish verbal matching task could be modified for English-speaking individuals and yield the expected female advantage. Another aim was to assess whether sex differences could be found on the visual-spatial matching task as found on other types of visual-spatial tasks (see Voyer, Voyer, & Bryden, 1995; Geary & DeSoto, 2001; Neumann, et al., 2007). Algan, et al. had suggested that the absence of sex differences was simply due to the relative ease of the visual-spatial matching task used in their study. The mean RT for the visual-spatial task was approximately 1200 ms, whereas for the verbal task it was approximately 2000 ms. Algan, et al. suggested that the ease of the visual-spatial task meant that it involved functioning at a predominantly perceptual level and that sex differences would only emerge if the task were to be performed at a predominantly cognitive level. Accordingly, the difficulty of the verbal and visual-spatial tasks was varied through the selection of stimuli (e.g., using more complex graphics) to examine whether sex differences interacted with task difficulty. It was hypothesized (H1) that the findings of Algan, et al. would be replicated when English words are used, wherein women would respond more rapidly than men on the verbal matching task. Given prior reports of better visual-spatial ability in men, faster responding by men (as compared with women) was predicted (H2) on the visual-spatial version of the matching task when complex graphics were used (e.g., Loring-Meier & Halpern, 1999; Halpern, 2000; Kimura, 2004). In view of the findings by Algan, et al., we did not expect to find any significant sex differences on the easy version of the visual-spatial matching task. Finally, the visual field of presentation was manipulated to examine laterality effects in the same manner as was undertaken by Algan, et al. (cf. Voyer, 1996). However, no specific hypotheses were proposed regarding the visual field of presentation because the experiment by Algan, et al. did not find any significant interaction between sex and this variable.

Primary Hypotheses

H1: Women will perform significantly better (faster RTs) than men on a verbal matching task at a high level of task difficulty.

H2: Men will perform significantly better (faster RTs) than women on a visual-spatial matching task at a high level of task difficulty.

Method

Participants

Thirty-nine right-handed (based on hand used for writing) undergraduates aged 21 to 37 years (*M* = 24.4 yr, SD = 4.6) were recruited from Bond University, Queensland, Australia and each were paid AU$20.00. The final sample of 19 men and 20 women confirmed English was their first and primary language. Students were randomly allocated to either the verbal or visual-spatial matching task. There were no significant differences between groups on background variables including sex, mean age or mean years of education (all *p*s > .05).

Apparatus

The cognitive matching tasks were presented on a Dell desktop computer, and vocal responses were recorded via a Sony Model DR220DP microphone headset. Analogous displays for the verbal and visual-spatial tasks were used (see F_1 for sample displays). The display is defined as a match or mismatch according to whether the pairs of letters form a word (verbal match) or the symbols are identical (visual-spatial match) in the vertical orientation. The central digit ensured fixation on the center of the display. The layout was the same as that used by Algan, et al. (1997), although the present experiment used different (English) words and visual-spatial graphics.

The verbal task display consisted of a central digit and two letter pairs above and to the left and right and one letter pair below and to either the left or right. Participants are required to perform a lexical decision on the letter string in the vertical orientation. Two letters were also presented in the other visual field, thereby adding to the task. The visual-spatial task display was similarly arranged, although graphic images were used. The central digit was selected at random from the digits 1 to 9 inclusive. The stimuli were presented on a CRT monitor set with a resolution of 800 x 600 pixels from a distance of 0.6 m. The central digit was a maximum of 15 pixels high x 10 pixels wide, the graphic/letters in each quadrant was a maximum of 40 pixels high x 40 pixels wide, and they were separated by a minimum diagonal gap of 17 pixels edge to edge.

Different displays were formed depending on whether it was a match or mismatch trial and whether the match occurred in the left (LVF) or right visual field (RVF) and on the same or opposite sides of the display. This resulted in LVF match, RVF match, across the left visual field (aLVF) match, across the right visual field (aRVF) match, LVF mismatch, and RVF mismatch trials. Only the displays showing a match were relevant to assessing the effects of the different hemispheric visual-field presentation conditions. The LVF and RVF displays formed a match on only one side of the display (i.e., left and right, respectively) and provided a test of right versus left visual-field advantage (e.g., faster response to LFV than RVF indicated a left visual-field advantage). The aLVF and aRVF displays may also have indicated some extent of the advantage to the left and right visual-field because one component of the match was always in one visual field (e.g., faster response to aRVF than aLVF suggested a left visual-field advantage).

Insert Fig. 1 here

To develop the stimuli for the verbal matching task, 192 high frequency four letter words (M = 1117.29 times per million) and 192 low frequency four letter words (M = 9.45

times per million) were selected (see Leech, Rayson, & Wilson, 2001). Fourteen of each of the high and low frequency words were randomly selected to serve as the LVF match, aLVF match, RVF match, or aRVF match. The first two letters of the word were placed above the digit on the display and the last two letters were below. A two-letter distractor used the first two letters of a randomly selected four-letter word with the restriction that the letters selected could not form an English word with the other letters. Mismatch trials were formed by selecting from the remaining words such that the display did not form an English word. The development of the verbal task stimuli resulted in 16 LVF match, 16 aLVF match, 16 RVF match, 16 aRVF match, 32 LVF mismatch, and 32 RVF mismatch displays for each of the high and low frequency (difficulty) words.

Stimuli for the visual-spatial task display were based on the graphics used in the *Raven's Progressive Matrices* test (cf. Raven, Raven, & Court, 2003; Colom, Escorial, & Rebollo, 2004). A total of 384 custom designed graphics were produced such that 192 were designed as simple and 192 complex by varying the number and complexity of the lines or shapes within each graphic (cf. Lynn & Tse-Chan, 2003; Abad, Colom, Rebollo, & Escorial, 2004). The graphics were allocated at random to match and mismatch conditions to produce 16 LVF match, 16 aLVF match, 16 RVF match, 16 aRVF match, 32 LVF mismatch, and 32 RVF mismatch displays for each of the high and low complexity (difficulty) graphics.

Procedure

Students completed the matching tasks individually seated 0.6 m from the computer monitor. They were instructed to indicate vocally and as quickly and accurately as possible for each display, first, the identity of the digit, and second, whether two of the three-letter pairs or graphics presented matched (i.e., formed an English word in the vertical orientation for the verbal task or were identical for the visual-spatial task) or mismatched. The timing parameters were based on Algan, et al. (1997). A trial began with a fixation cross for 2000 msec. after which the visual display was presented for either 600 msec. (verbal task) or 350 msec. (visual-spatial task). An 8000 msec. interval followed during which students could indicate their response. Participants first completed 16 practice trials and next completed trials for the low difficulty condition, followed by the high difficulty condition in counterbalanced order. Within each difficulty condition, the trials were presented in two blocks of 56 trials. Each block contained a randomized order of 7 LVF match, 7 across LVF match, 7 RVF match, 7 across RVF match, 14 LVF mismatch and 14 RVF mismatch displays for each of the difficulty conditions.

Results

Reaction time (RT) was assessed only for trials in which the participants (a) correctly identified the digit and (b) made a correct match or mismatch response. The median RT for each participant in each condition was calculated to reduce the impact of skewness in the RT distributions. Accuracy was calculated as the mean proportion of correct responses for those trials on which the participants correctly identified the digit in the center of the display. To examine performance as a function of training, means were calculated for the first 28 trials (Block 1) and the second 28 trials (Block 2) in each difficulty condition.

Initial analyses compared match and mismatch trials via 2 x 2 x 2 x 2 x 2 (Sex x Task x Difficulty x Match x Block) Analyses of Variance (ANOVAs). RT was significantly faster on the visual-spatial matching task than on the verbal matching task. RT was also significantly faster for the low difficulty condition and across blocks. As shown in Table 1, sex interacted significantly with all these factors. The significant three-way interaction relevant to H1 and H2 is depicted in F_2 and was examined via <u>post hoc</u> (2-tailed) <u>t</u> tests with correction for Type 1 error using the Dunn-Šidák multiplicative inequality correction. Women responded more rapidly than men during the verbal matching task, although this difference was limited to Block 2 (t_{37} = 6.20, p < .001). There were no significant sex differences for any block on the visual-spatial task.

Insert Tables 1 and 2 and Figs. 2 and 3 here

The analyses for mean proportion correct are presented in Table 2. The only significant effect involving sex was a four-way interaction. The interaction is shown in F_3 which reveals that women made significantly more correct responses than men for match trials in the low difficulty condition for Block 1 (t_{37} = 3.61, p < .01) and men made significantly more correct responses than women on mismatch trials in the high difficulty condition in Block 2 (t_{37} = 3.16, p < .05).

A second set of analyses assessed laterality effects by examining the visual field of presentation during the match trials using 2 x 2 x 4 x 2 x 2 (Sex x Task x Visual Field x Difficulty x Block) ANOVAs. As shown in Table 3, RT differed as a function of sex, as reflected in significant two-way and three-way interactions. F_4 shows that on the verbal matching task, women exhibited a significantly faster RT from Blocks 1 to 2 (t_{19} = 2.96, p < .05), whereas men exhibited a significantly slower RT across blocks (t_{18} = 2.28, p = .07). No significant differences across blocks were found on the visual-spatial matching task. The significant interaction between sex and visual field resulted from a nonsignificant effect of visual field among women, but a significant effect of visual field among men (F_5). Comparisons for men showed that RT was significantly faster in the LVF condition than in the RVF condition (t_{18} = 2.77, p < .05), and in the aRVF condition than in the aLVF condition (t_{18} = 5.72, p < .01). The analyses for mean proportion correct yielded a complex relationship between the visual field of presentation and other factors. However, as shown in Table 4, none of the main effects or interactions involving sex was significant.

Insert Tables 3 and 4 and Figs. 4 and 5 here

Discussion

The present study revealed a number of significant sex differences on the differing cognitive tasks. The sex differences found with response accuracy were less extensive than those found with RT. Importantly, sex did not emerge merely as a significant main effect, but interacted with one or more of the orthogonally manipulated variables. The most important of these was the type of task, in that women performed significantly better than men on the verbal matching task in accord with H1, whereas in contrast to H2, no significant sex difference was observed on the visual-spatial matching task. This interaction between sex and type of task cannot be accounted for by sex differences in general task demands (e.g., speed of responding; Silverman, 2006) because the same stimulus display format and response requirements were used for the verbal and visual-spatial versions of the task. The present experiment shows that sex can have a directional (qualitative) effect on how other independent variables operate (e.g., type of task), rather than merely influencing magnitude (quantitative) effects (Furedy & Pöğün, 2001).

Another qualitative difference that emerged was the interaction between sex and performance across trial blocks. During the match trials, women's verbal task performance improved over trial blocks, manifesting the practice effect that one would expect on the basis of learning a particular cognitive task. In contrast, men's performance on the verbal task actually deteriorated as shown by the slowing of RT over blocks. This interaction appears to be crucial to finding sex differences on the verbal task because performance in men and women did not differ on the first trial block.

No significant sex differences emerged on the visual-spatial version of the matching task. In accord with H2, it had been predicted that increasing the difficulty level would yield better performance for men as has been found with other types of visual-spatial tasks (e.g., Voyer, Voyer, & Bryden, 1995; Geary & DeSoto, 2001; Neumann et al., 2007). Increasing task difficulty did produce a significant effect (i.e., longer RTs), but like Algan, et al. (1997), responses on the visual-spatial task were faster than for the verbal task. The RT difference may reflect a qualitative difference between the verbal and visual-spatial matching tasks, with the former having a greater conceptual component which involves a decision on whether a word is formed, a component not present in the more perceptual process of merely matching two graphic images. The failure of trial blocks (stage-of-acquisition) to affect visual-spatial matching task performance is consistent with this interpretation. For further work it may be necessary to employ more complex Raven's visual-spatial stimuli, which would require participants (men vs women) to mentally rotate one image relative to another in order to identify whether a match or mismatch is present. This would involve a mental rotation task in which prior research has shown reliable sex differences, with better performance exhibited by men than women (e.g., Collins & Kimura, 1997; Parsons, Larson, Krantz, Thiebaux, Bluestein, Buckwalter, et al., 2004; Kaufman, 2007; Hamilton, 2008).

The present experiment revealed a number of insights regarding sex differences in verbal and visual-spatial cognitive functions. It is also prudent to note some limitations in the research and to point to areas of further research. The relatively small sample size used in the present experiment suggests that a replication study is warranted using a larger group of participants. In particular, the interaction between sex and visual field of presentation requires replication in light of the marginally significant effect found in the present experiment ($p = .049$) and given that Algan, et al. (1997) did not report any such interaction in their experiment with Turkish adults. However, the observed results of more extensive laterality effects for men than for women is consistent with previous findings (e.g., see Halpern, 2000; Halpern & LaMay, 2000; Furedy & Pöğün, 2001; Weiss, et al.; Boyle & Saklofske, 2004; Ecuyer-Dab & Robert, 2004).

In conclusion, the present results suggest that there is a processing speed advantage for men when stimuli are presented in the left visual field rather than in the right visual field. Future research could vary the task to provide a more controlled assessment of laterality effects. The exposure duration during the verbal task of 600 ms may be sufficiently long for participants to move their eyes to different locations of the display. Therefore, a briefer exposure duration is recommended, as well as additional controls (e.g., the measurement of eye movements). Still, it is clear that for an unambiguous interpretation of performance on cognitive tasks, the effects of sex differences must be taken into account when designing experiments into human cognition.

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TABLE 1

SIGNIFICANT MAIN EFFECTS AND INTERACTIONS RESULTING FROM THE ANALYSIS OF VARIANCE OF RESPONSE TIME FOR MATCH TRIALS AND MISMATCH TRIALS

Source	*df*	*F*	*p*	η_p^2
		Between subjects		
Task	1, 35	32.13	<.0005	.48
		Within subjects		
Difficulty	1, 35	11.65	.002	.25
Match	1, 35	11.67	.002	.25
Sex x Block	1.35	7.19	.01	.17
Task x Match	1, 35	6.04	.02	.15
Difficulty x Block	1,35	5.14	.03	.13
Sex x Task x Block	1.35	6.42	.02	.16
Task x Difficulty x Match	1, 35	10.71	.002	.23
Task x Match x Block	1,35	5.98	.02	.15
Difficulty x Match x Block	1,35	7.13	.01	.17
Sex x Difficulty x Match x Block	1,35	7.74	.009	.18

TABLE 2

SIGNIFICANT MAIN EFFECTS AND INTERACTIONS RESULTING FROM THE ANALYSIS OF VARIANCE OF RESPONSE ACCURACY FOR MATCH TRIALS AND MISMATCH TRIALS

Source	*df*	*F*	*p*	η_p^2
		Within subjects		
Difficulty	1, 35	95.91	<.0005	.73
Match	1, 35	46.49	<.0005	.57
Task x Match	1, 35	35.42	<.0005	.50
Task x Difficulty	1, 35	9.75	.004	.22
Match x Difficulty	1, 35	7.21	.01	.17
Match x Block	1,35	6.84	.01	.16
Difficulty x Block	1,35	18.27	<.0005	.34
Task x Match x Difficulty	1, 35	66.49	<.0005	.66
Task x Difficulty x Block	1,35	15.71	<.0005	.31
Sex x Match x Difficulty x Block	1,35	6.72	.01	.16

TABLE 3

SIGNIFICANT MAIN EFFECTS AND INTERACTIONS RESULTING FROM THE ANALYSIS OF VARIANCE OF RESPONSE TIME FOR MATCH TRIALS AS A FUNCTION OF THE VISUAL FIELD OF PRESENTATION

Source	*df*	*F*	*p*	η_p^2
Between subjects				
Task	1, 35	28.36	<.0005	.45
Within subjects				
Difficulty	1, 35	14.02	.001	.29
Visual Field	3, 105	4.44	.01	.11
Difficulty x Block	1, 35	7.92	.01	.18
Sex x Block	1, 35	8.13	.01	.19
Sex x Visual Field	3, 105	2.81	.05	.07
Visual Field x Task x Block	1, 105	4.69	.01	.12
Sex x Task x Block	1, 35	5.44	.03	.14

TABLE 4

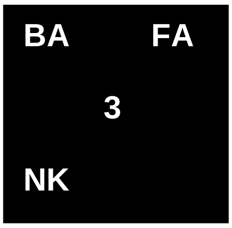
SIGNIFICANT MAIN EFFECTS AND INTERACTIONS RESULTING FROM THE ANALYSIS OF VARIANCE OF RESPONSE ACCURACY FOR MATCH TRIALS AS A FUNCTION OF THE VISUAL FIELD OF PRESENTATION

Source	*df*	*F*	*p*	η_p^2
		Between subjects		
Task	1, 35	17.67	<.0005	.34
		Within subjects		
Visual Field	3, 105	9.51	<.0005	.21
Difficulty	1, 35	10.94	.002	.24
Task x Visual Field	3, 105	6.52	.001	.16
Task x Difficulty	1, 35	12.51	.001	.26
Difficulty x Block	1, 35	8.43	.01	.19
Visual Field x Block	3, 105	4.36	.01	.11
Task x Visual Field x Difficulty	3, 105	4.77	<.004	.12
Task x Difficulty x Block	1, 35	9.59	<.004	.22
Task x Visual Field x Difficulty x Block	3, 105	8.67	<.0005	.20

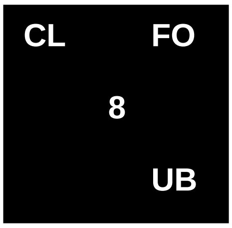
Figures

Fig. 1. Examples of displays for stimulus presentations on the verbal matching task (top panel) and visual-spatial matching task (bottom panel)

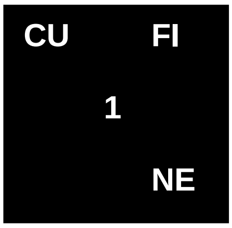
Verbal matching task



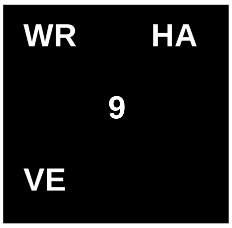
Left visual field match



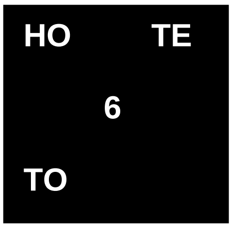
Across left visual field match



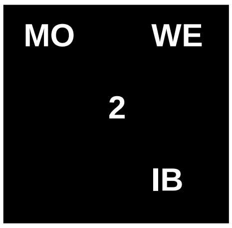
Right visual field match



Across right visual field match

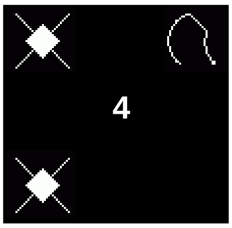


Left visual field mismatch

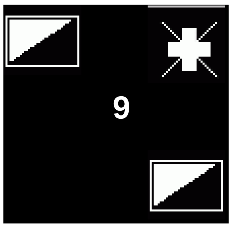


Right visual field mismatch

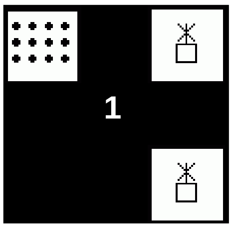
Visual-spatial matching task



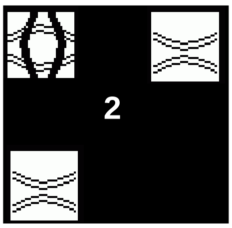
Left visual field match



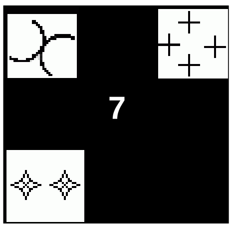
Across left visual field match



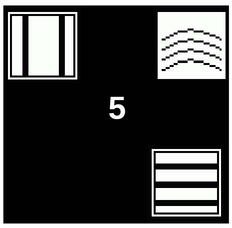
Right visual field match



Across right visual field match



Left visual field mismatch



Right visual field mismatch

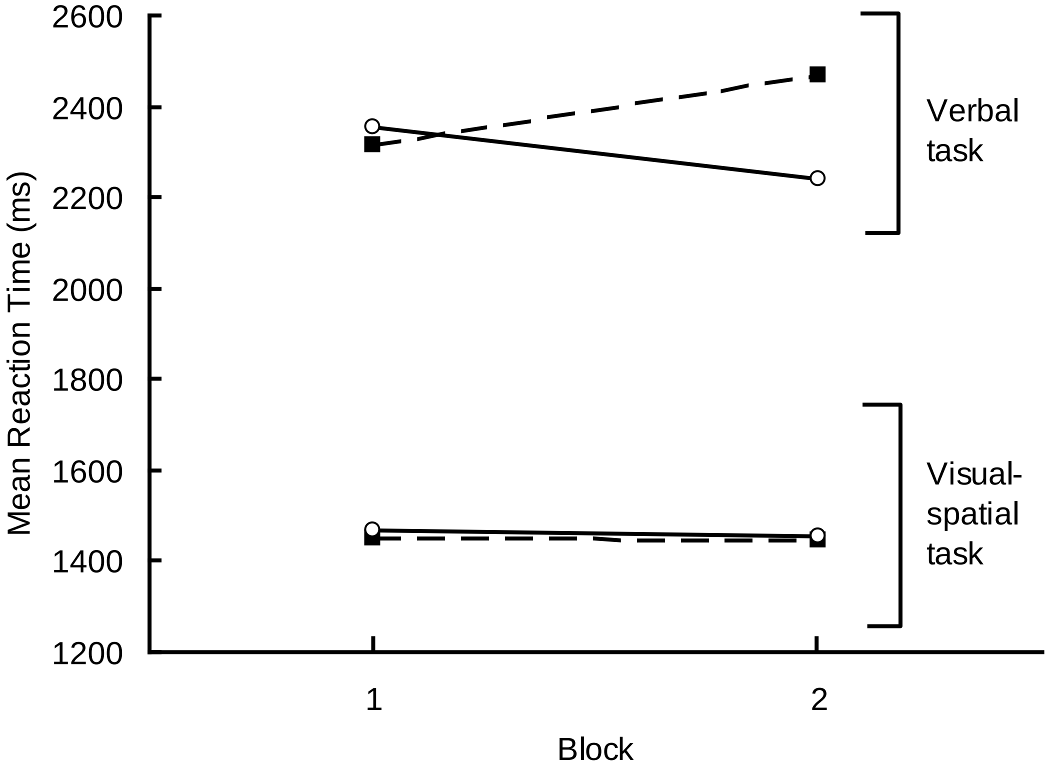


Fig. 2. Mean reaction time for verbal and visual-spatial matching tasks as a function of sex and block. Solid circle+dotted line = Men; Hollow circle+solid line = Women.

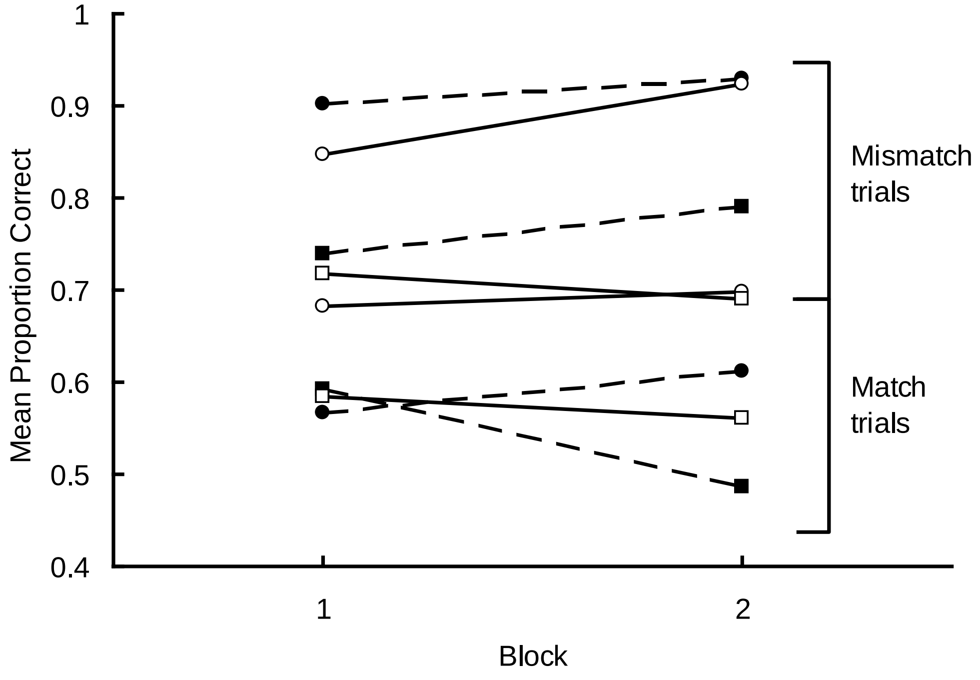


Fig. 3. Mean proportion correct by men and women as a function of match trial type, task difficulty and trial block. Solid circle+dotted line = Men-Low Difficulty; Solid square+dotted line = Men-High Difficulty; Hollow circle+solid line = Women-Low Difficulty; Hollow square+solid line = Women-High Difficulty.

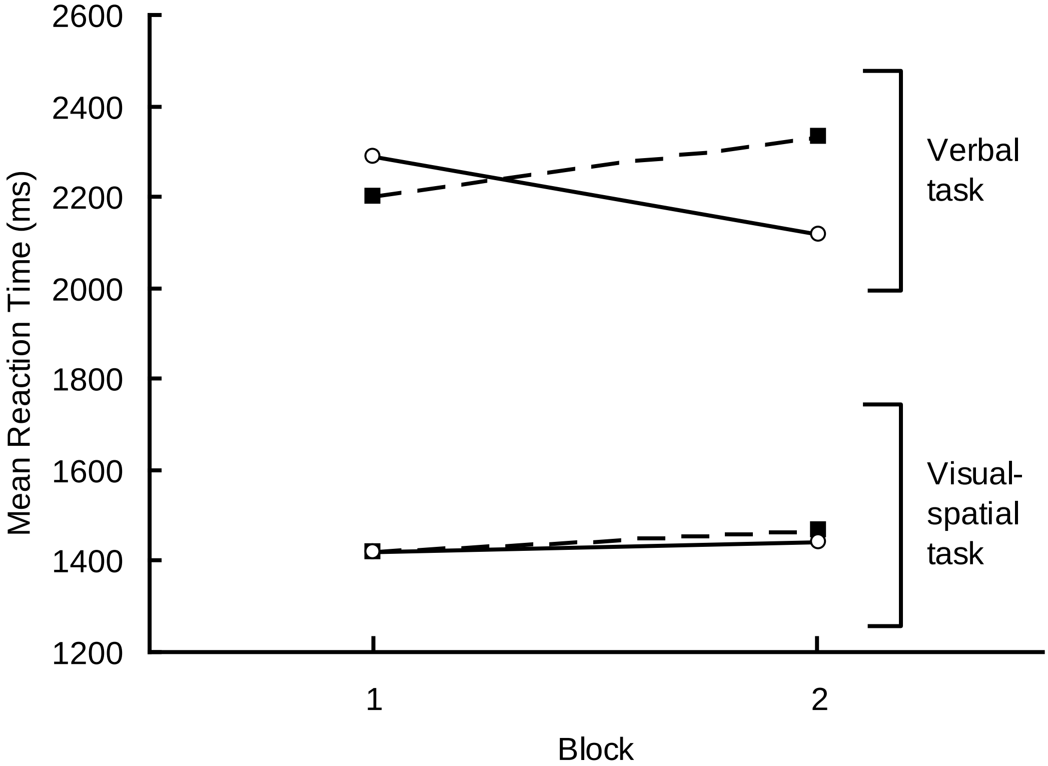


Fig. 4. Mean reaction time for verbal and visual-spatial matching tasks as a function of sex and block for the match trials only. Solid square+dotted line = Men; Hollow circle+solid line = Women.

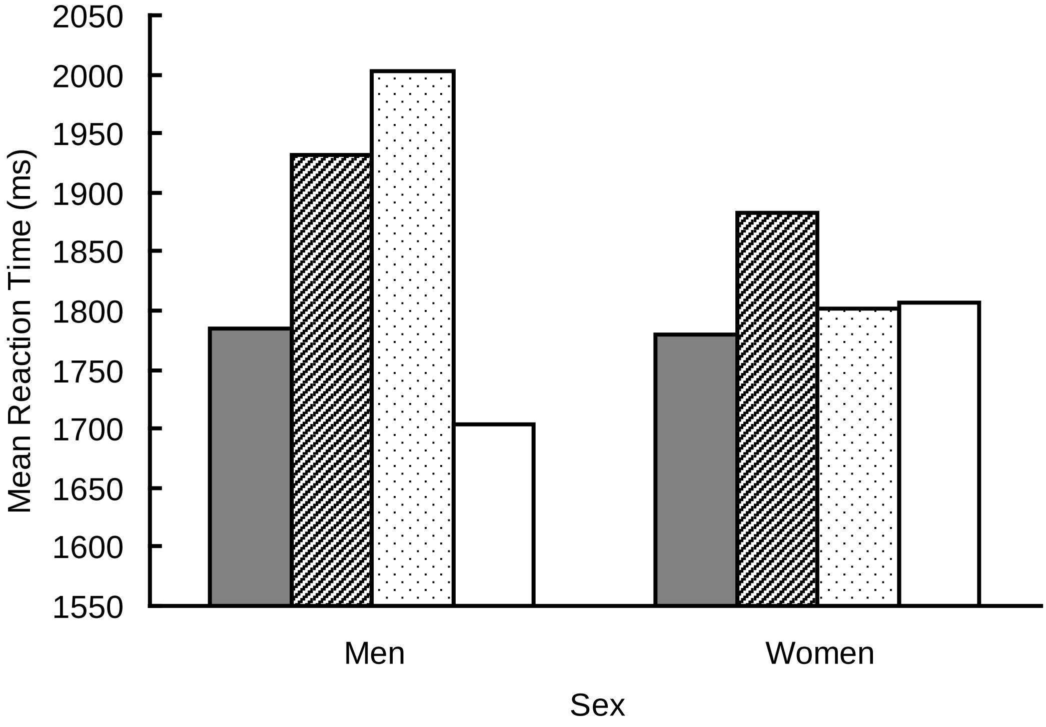


Fig. 5. Mean reaction time for men and women as a function of hemispheric presentation condition during the match trials. Solid grey = Left visual field; Diagonal lines = Right visual field; Dots = Across left visual field; Solid white = Across right visual field.