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Original Article

Testing Predictions from the Hunter-Gatherer Hypothesis – 2: Sex Differences in the Visual Processing of Near and Far Space

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Abstract: Here, in the second of two linked reports, we focus on sex differences in visual processing. Study 1 presented a time estimation task in virtual space and generated the predicted Space*Sex interaction with men performing significantly better in far than in near space. Study 2 used a laboratory-based puzzle completion task in which participants saw their hands and the puzzle in far or near space. This time women performed significantly better in near than far space. Study 3 simplified the puzzle completion task. Once again the predicted Space*Sex interaction was significant but with both sexes showing significantly different performances: women better in near, men in far space. These findings are compatible with an evolutionary origin as predicted by the hunter-gatherer hypothesis. Far and near space are processed in the ventral and dorsal streams, two cortical regions more widely known as the "what" and "where" visual systems. To those traditional descriptions we suggest adding that the two streams are sex-dimorphic, with the ventral "there" system interacting with far space and favored in men and the dorsal "here" system interacting with near space and favored in women. Future studies of visual systems should consider the impact of sex differences and the spatial location of stimulus presentations.

Keywords: hunter-gatherer hypothesis; sex differences; visual processing; far and near space; dorsal and ventral cortical streams; two visual systems.

Introduction

Silverman and Eals (1992) proposed the hunter-gatherer hypothesis as an evolutionary explanation for sex differences in spatial ability. They argued that sex differences in task performance have arisen from a process of natural selection that favored hunting-related skills in men and gathering–related skills in women. While the hypothesis cannot be tested directly we can test its predictions and we have adopted this approach in a series of studies aimed to generate predictions that are novel and testable. In this, the second of two parallel reports, we focus on predicted sex differences in the visual processing of far and near space. In the first report we addressed sex differences in motor control (Sanders and Walsh, 2007). In both cases we were able to demonstrate the predicted sex differences and to identify from the literature neural bases for those differences.

We began with the premise that selection for hunting skills would favor men with good processing of visual input from far (extrapersonal) space for detecting suitable prey and accurately aiming a missile, together with good proximal arm muscle performance for throwing the missile at the prey. On the contrary, selection for gathering skills would favor women with good processing of visual input from near (peripersonal) space for the detection of appropriate items together with good distal hand muscle performance for grasping those items. Thus for visual processing we would expect an interaction between Space and Sex with women performing better in near and men in far space. For motor control we would expect women to favor the hand and men the arm, a prediction that we have confirmed (Sanders and Walsh, 2007).

Here we report three studies that focus on sex differences in the visual processing of information from far and near space for which no published studies appear to exist. Study 1 was conducted via the Internet using a time estimation task in virtual space while Study 2 and Study 3 were laboratory-based using a puzzle completion task. In each case we predicted a Space*Sex interaction arising from women performing better with visual input from near space and men with visual input from far space. Data were subjected to appropriate analyses of variance and significant interactions were explored with t-tests using 1-tailed tests for our directional predictions and 2-tailed tests for other comparisons.

Study 1

Study 1 was conducted via the World Wide Web. Male and female participants were required to make spatiotemporal judgments in far and near virtual space. Schiff and Oldak (1990) used real life film of approaching vehicles projected in a laboratory and found that women were less accurate than men at judging time to arrival because they tended to underestimate. The effect persisted when the authors removed the element of personal risk by using film of a tabletop toy car approaching a gateway. This task was suitable for our study because it could be presented visually in both far and near space with the same required response, a key press, thus ensuring that the cognitive demands and motor movement were constant and only the source of the visual input (far and near space) varied between the conditions. We collected our data using a two-dimensional representation of a three-dimensional image presented in virtual space via the Internet. The task was presented as a computer game in which potential participants were asked to judge the time to arrival at a docking station of a toy UFO that hovered above a tabletop.

Materials and Methods

Participants

The target participants were men and women with a minimum age of 18 years. The Web address for the study was spread through a network of informal contacts, principally via email. Potential participants logged onto the site and decided whether or not to participate and, if they completed the task, whether or not to submit their data. Submissions were received from 166 participants. Nine were discarded because the data were incomplete, or because the arrival time estimates fell outside reasonable limits (i.e., those corresponding to times when the UFO was visibly distant from the docking station), or because the submitted data came from the same computer and/or email address as a previous submission. There remained submissions from 93 men and 64 women. We analyzed the data from all the women and from the first 64 male respondents. The study was approved by the London Metropolitan University Psychology Department Ethics Committee. On-screen instructions indicated that by submitting their data participants were giving consent for it to be used in the study.

Task and procedure

Via the website, potential participants could access a program, written by KS in Java Script, which appeared as two html pages: the Instructions and the Task. On the Task page, participants were presented with a 2-D representation of a 3-D scene in virtual space. A hovering toy UFO projected a spot of light onto a tabletop. The UFO then moved obliquely towards the participant as it traveled to a docking station. Before reaching the docking station the UFO and its spotlight disappeared and participants were asked to press their space bar at the precise moment they thought the UFO's spotlight would have coincided with the centre of the, still visible, docking station.

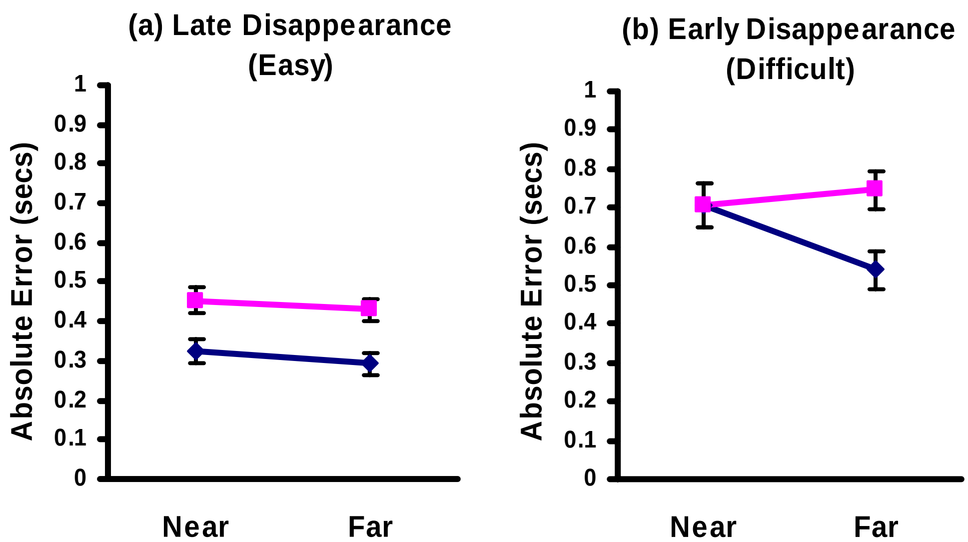
Three aspects of the UFO's trajectory, spatial location (far/near), starting side (left/right) and disappearance time (early/late), were manipulated as independent variables. Space was represented by a receding table with one chair on its near left side and another in the centre of the far end. The orientation of the scene indicated that the participant was sitting at the near end of the table. From this position, given the size of the chairs in relation to the table, it was apparent that a participant would be able to reach the full width and at least across the nearest third, but not quite the nearest half of the table. In the far condition the UFO appeared at the distant end of the table in one corner and traveled towards a docking station in the middle of the opposite side. In the near condition the UFO appeared at the edge of the table in the middle of one side and traveled towards a docking station in the near corner of the opposite side. Thus, in the far condition, the entire trajectory of the UFO was beyond reaching distance in far (extrapersonal) space, whereas, in the near condition, all but the starting point was in near (peripersonal) space. Side was represented by the starting point, left or right, of the journey made by the UFO. Disappearance was determined by the point in the journey when the UFO disappeared. The total journey time was fixed at five seconds. In the early (more difficult) condition the UFO disappeared 2.53 seconds before docking while in the late (easier) condition it disappeared 1.40 seconds before docking. This "level of difficulty" factor was introduced because demonstrations of sex differences may be masked by using tasks that are too easy or too difficult to differentiate the performances of men and women (Sanders, Sjodin, and de Chastelaine, 2002).

We used a mixed design: Sex was a between participants factor with two independent groups, women and men; while Space, Side and Disappearance were within participants factors with repeated measures on near/far, left/right and early/late respectively. These three factors were tested over eight repeated measures trials: near-left-early, near-left-late, near-right-early, near-right-late, far-left-early, far-left-late, far-right-early and far-right-late that were presented in a random sequence to the participants.

Results and Discussion

The time estimations were subjected to a 4-way ANOVA with Sex as a between participants factor and Space, Side and Disappearance as within participants factors. With performance collapsed across all conditions the male grand mean score (5.127 seconds) was closer to the correct value of 5 seconds than the female grand mean score (4.640 seconds) and this main effect of Sex was significant ($F_{1,\ 126} = 34.433$, $p < 0.001$). This finding confirms the report by Schiff and Oldak (1990) that men are more accurate than women who tend to underestimate time of arrival. However, our major interest here is the accuracy of male and female arrival time estimates in far and near space so for all subsequent analyses we have used absolute error (time estimate minus 5 with the sign ignored) as the dependent variable. A 4-way ANOVA based on the absolute error scores revealed main effects of Sex ($F_{1,\ 126} = 6.652$, $p = 0.011$) with men more accurate than women, Space ($F_{1,\ 126} = 4.642$, $p = 0.033$) with participants more accurate in the near condition and Disappearance ($F_{1,\ 126} = 123.372$, $p<0.001$) which arose because participants were more accurate in the easier late than the more difficult early condition. There were also significant Space*Sex ($F_{1,126} = 6.125$, $p = 0.015$) and Space*Disappearance*Sex ($F_{1,126} = 6.038$, $p = 0.015$) interactions. The Disappearance factor effectively manipulates level of difficulty. Comparing the early with the late condition shows that participants see the UFO for less time (2.47 compared with 3.60 seconds) and have to remember its speed for a longer time (2.53 compared with 1.40 seconds). It is known that level of difficulty can be a critical factor in the demonstration of sex differences (Sanders, Sjodin, and de Chastelaine, 2002) so we analyzed the early (difficult) and late (easy) disappearance data separately.

Figure 1. Study 1: Mean (+/- SEM) of the absolute error (time to arrival estimate minus 5 with sign ignored) in seconds recorded with (a) late disappearance (easy) and (b) early disappearance (difficult) conditions for men (blue/ darker grey line and diamonds) and women (pink/ lighter grey line and squares) with the visual information presented via the Internet in near (peripersonal) and far (extrapersonal) virtual space.



A 3-way ANOVA based on the absolute error data from the easy late disappearance condition reveal a significant main effect of Sex ($F_{1,126}$ = 13.777, $p<0.001$) with men more accurate than women (Fig. 1a). The only other significant outcome was the main effect of Side ($F_{1,126}$ = 3.963, p = 0.049) with overall accuracy better when the UFO moved from right to left, but the effect of Side was not significant for either sex alone (women t_{63} = 1.903, p = 0.062; men t_{63} = 0.902, p = 0.370, both two-tailed). The 3-way ANOVA on the absolute error data from the difficult early disappearance condition reveal only one significant outcome, the Space*Sex interaction ($F_{1,126}$ = 7.635, p = 0.007). As seen in Figure 1b, this interaction arose because men were more accurate when the UFO was moving in virtual far space (t_{63} = 3.762, p = 0.001, one-tailed) while women were marginally more accurate in near space although the difference was not significant (t_{63} = 0.721, p = 0.237, one-tailed).

In summary, data from the more difficult early disappearance condition confirmed two of our three predictions; the Space*Sex interaction and the greater accuracy of men in far than in near space, but not that women were more accurate in near than in far space. In addition, the combined data confirmed the Schiff and Oldak (1990) report of a sex difference in the estimation of time to arrival with men more accurate than women and extended this finding from a real world laboratory-based study to the virtual world of the Internet. One other finding emerged from the complex interactions that occurred between Sex, Space, Side and Disappearance; performance was better when the UFO moved from right to left rather than from left to right. At present we have no explanation for this right/left difference other than the possibility that the predominant use of the right hand to press the space bar produced a priming effect similar to that reported by Frassinetti, Rossi and Ladavas (2001). However, as noted above, the effect of Side disappeared when the male and female data were analyzed separately.

Study 2

In Study 2 we investigated sex differences in the visual processing of information from far and near space in the real world space of a laboratory. Participants were required to arrange pieces of foam-board to form a square while viewing an image of their hands and the pieces of board projected onto a closely placed monitor for the near space condition or onto a more distant wall-mounted screen for the far space condition. Once again we predicted a Space*Sex interaction arising from women performing better with visual input from near space and men with visual input from far space.

Materials and Methods

Participants

Forty participants, 20 women and 20 men, were recruited as an opportunity sample from among our University students. The study was approved by the London Metropolitan University Psychology Department Ethics Committee. All participants gave informed written consent and were aware that they could withdraw from the study at any time. None withdrew.

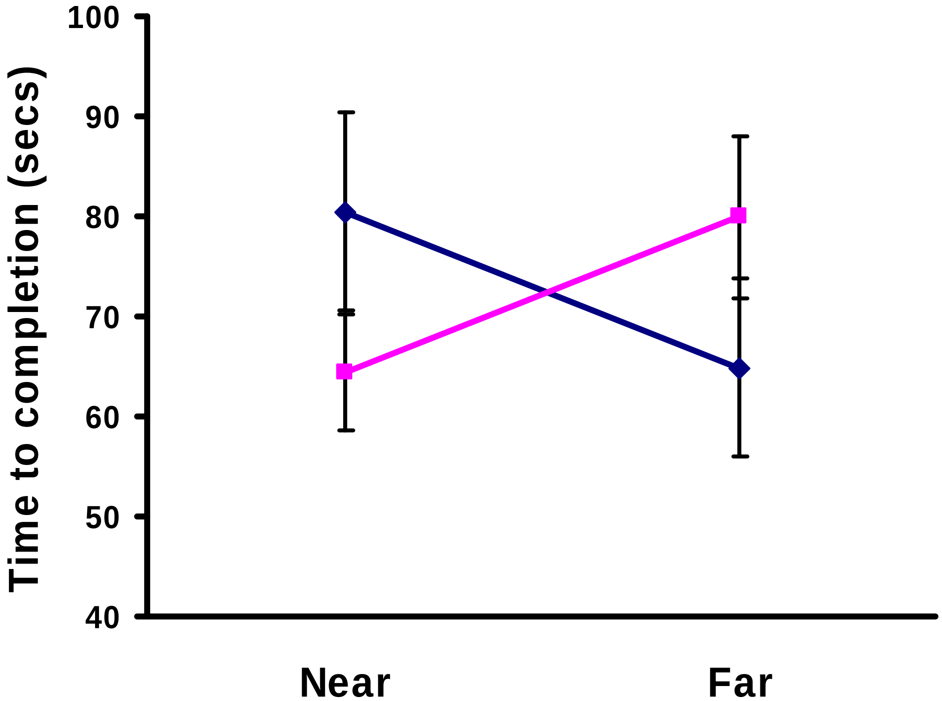
Task and procedure

Participants were required to correctly assemble simple puzzles constructed from 3 mm thick white foam-board. Each puzzle was made by cutting a 100 mm square of board into five pieces using combinations of curved and straight lines. The pieces were displayed and assembled on a large sheet of matt black card that covered the table closest to the seated participant. At the start of each trial the five pieces were arranged in the same randomly determined positions in front of the participant. A curtain, suspended from a wooden frame, prevented participants from looking directly at their hands or the puzzle. Instead a webcam was used to display an image of the puzzle and the participant’s hands. In the near space condition the image was displayed on a 380 mm monitor placed 500 mm from the participant. By looking straight ahead, across the top of the framed curtain, participants could see the entire monitor screen but not their hands or the puzzle. In the far space condition, the image was projected onto a wall-mounted screen placed 2000 mm from the participant. By looking straight ahead, across the top of the framed curtain and the monitor, participants could see the entire wall-mounted screen but not their hands or the puzzle. The size of the image on the wall-mounted screen was adjusted so that it subtended the same visual angle as the image on the monitor. We used a mixed design with Sex as a between participants factor and Space as a within participants factor with repeated measures in the far and near conditions. The order of the far and near conditions was counterbalanced across participants. The time taken to complete the puzzle was recorded with a stopwatch to the nearest 0.01 seconds.

Results and Discussion

The puzzle completion time data were subjected to a 2-way ANOVA with Sex (male/ female) as a between participants factor and Space (far/ near) as a within participants factor. The main effects of Sex and Space were not significant (sex $F_{1,38}$ = 0.002, p = 0.999; space $F_{1,38}$ = 0.000, p = 0.999). However, as predicted, there was a significant Space*Sex interaction ($F_{1,38}$ = 4.979, p = 0.032) that arose because women completed the puzzles faster in near space whereas men were faster in far space (Fig. 2). The far/near space effect was significant for women (t_{19} = 1.936, p = 0.034, one-tailed) but not for men (t_{19} = 1.365, p = 0.094, one-tailed).

Figure 2. Study 2: Mean (+/- SEM) time to complete puzzle in seconds for men (blue/ darker grey line and diamonds) and women (pink/ lighter grey line and squares) in near (peripersonal) and far (extrapersonal) space with free movement of the hand and arm.



Thus the finding from Study 2 replicates in the laboratory the predicted Space*Sex interaction that we found for virtual space in Study 1. However, whereas in Study 1 the interaction arose because men performed significantly better in far than near space, this time, women performed significantly better in near space while the far/near difference was not significant for men. In Study 3 we hoped to demonstrate significant far/near differences concurrently for men and women by repeating Study 2 with some modifications, including procedures to control muscle use.

Study 3

In Study 2 participants used their hands and arms freely to complete the puzzles. For Study 3 we decided to control muscle usage because sex differences in the use of hand and arm have been reported (Sanders and Walsh, 2007): women are better with their hands but men with their arms. Consequently participants were required to complete the puzzles separately in the far and near conditions using either hand (wrist and finger) or arm (upper arm and shoulder) movements. Hence, in addition to the predicted Space*Sex interaction, with women performing better in near and men in far space, we also predicted a Muscle*Sex interaction with women performing better with their hands and men with their arms.

Materials and Methods

Participants

Sixty participants, 30 women and 30 men, were recruited as an opportunity sample from among our University students. The study was approved by the London Metropolitan University Psychology Department Ethics Committee. All participants gave informed written consent and were aware that they could withdraw from the study at any time. None withdrew.

Task and procedure

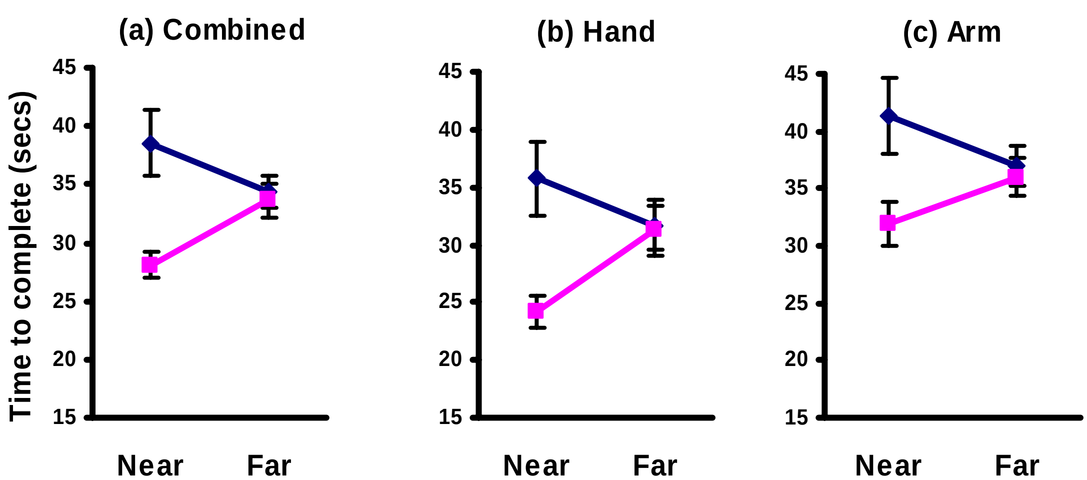
The basic task and procedure were similar to those used in Study 2 but, anticipating that restricting movement to either hand or arm use would increase task difficulty, completion of the puzzles was made easier. As before, participants were required to correctly assemble five-piece foam-board puzzles to form a 100 mm square but, this time, a puzzle was judged to be completed when all five pieces were correctly assembled within a 105 mm square outline, i.e. perfect contact between the pieces was not required. As a second aid, a drawing of the completed puzzle, which participants were instructed to use as a guide, was displayed just beyond the five pieces in their starting positions.

We used a mixed design. Sex was a between participants factor with two independent groups, women and men; Space and Muscle were within participants factors with repeated measures hand/ arm and far/ near respectively. The far and near conditions were established as in Study 2. For the hand condition participants were instructed to rest their forearms on the edge of the table and to complete the puzzle using movements of their fingers and wrists. In the arm condition participants were instructed to hold the pieces between their first finger and thumb but to restrict all other movements to the muscles of the upper arm and shoulder. As a reminder not to move wrists or fingers, the participants in the arm condition wore skating wrist protectors. Participants completed one of the four puzzles in each of four conditions: far-hand, near-hand, far-arm and near-arm. The sequence in which the puzzles were presented was randomized across participants and the time taken to complete them was recorded with a stopwatch to the nearest 0.01 seconds.

Results and Discussion

The puzzle completion time data were submitted to a 3-way ANOVA with Space (far/ near) and Muscle (hand/ arm) as within participant factors and Sex as a between participants factor.

Figure 3. Study 3: Mean (+/- SEM) time to complete puzzle in seconds for men (blue/ darker grey line and diamonds) and women (pink/ lighter grey line and squares) in near (peripersonal) and far (extrapersonal) space using (a) combined hand and arm data, (b) hand data and (c) arm data.



As seen in Figure 3a, there was a significant Space*Sex interaction ($F_{1,58}$ = 11.838, p = 0.001) that arose because men, as predicted, completed puzzles faster in the far condition (t_{29} = 1.949, p = 0.031, one-tailed) whereas women performed better in the near condition (t_{29} = 3.013, p = 0.003, one-tailed). In addition there were significant main effects of Sex ($F_{1,58}$ = 6.302, p = 0.015) and Muscle ($F_{1,58}$ = 16.352, p = 0.001) that arose because overall completion times were faster for women than men and faster for the hand than the arm condition (compare Fig. 3b and c). Contrary to expectation, the Muscle*Sex and Muscle*Space*Sex interactions were not significant; however, observation during the study indicated that our control for muscle use was not effective. While the instructions to restrict movement to hand or arm were followed in preliminary tests, in the main study participants used combinations of hand and arm muscle movements.

On finding that the Muscle (hand/ arm) condition effectively manipulated difficulty we used 2-way ANOVA to analyze the hand and arm data separately. Both analyses generated similar outcomes (Fig. 3b and c), a significant main effect of Sex (hand: $F_{1,58} = 6.50$, $p = 0.013$; arm: $F_{1,58} = 4.47$, $p = 0.039$) with women faster overall than men and a significant Space*Sex interaction (hand: $F_{1,58} = 5.75$, $p = 0.020$; arm: $F_{1,58} = 4.23$, $p = 0.044$) with women faster in near space and men faster in far space. On these reduced data sets the far/near difference was significant for women with the hand data ($t_{29} = 3.00$, $p = 0.006$) but not for the arm data ($t_{29} = 1.53$, $p = 0.138$) while the faster performance of men in the far condition failed to reach significance (hand: $t_{29} = 1.01$, $p = 0.319$; arm: $t_{29} = 1.40$, $p = 0.172$).

We had expected the muscles used to influence performance because women have been reported to perform better with their hands and men with their arms (Sanders and Walsh, 2007). However, in the present study neither the Muscle*Sex or the Muscle*Space*Sex interactions were significant. Observation of participant behavior during data collection revealed the reason. Although the minimal constraints that we used to promote use of either the hand or the arm were sufficient during preliminary tests, in the main study participants either forgot or ignored those instructions. Hence the absence of a muscle effect is not surprising because the hand and arm conditions in Study 2 did not represent robust distinctions between separate hand and arm muscle use. Nevertheless, the use of combined hand and arm data for the space analysis remains appropriate because the distinction between far and near was sound. Therefore the findings from Study 3, have reconfirmed the Space*Sex interaction with women performing better in near and men in far space.

General Discussion

Behavioral sex differences and implications for the hunter-gatherer hypothesis

Sex-dimorphic motor tasks that are typically cited as support for the hunter-gatherer hypothesis, e.g. targeted throwing at which men excel (Watson and Kimura, 1991) and fine motor movement at which women excel (Nickolson and Kimura, 1996; Sanders and Kadam, 2001) confound task demands, motor responses and spatial location. Here we have reported three studies in which spatial location was systematically varied between near (peripersonal) and far (extrapersonal) while task demands and motor responses were held constant. We argued that selection for hunting skills should favor men with good processing of visual input from far (extrapersonal) space to facilitate the detection of suitable prey and for accurately aiming a missile. However, selection for gathering skills would favor women with good processing of visual input from near (peripersonal) space to facilitate the detection and grasping of appropriate items. Thus we predicted that women would perform better when stimuli were presented in near space and men when the stimuli were in far space.

With the previous confounds removed, each of our studies confirmed the predicted Space*Sex interaction, arising because men performed significantly better with visual information from far space in Studies 1 and 3 while women performed significantly better with information from near space in Studies 2 and 3. It is notable that these sex differences were detected not only in the real space of laboratory-based tasks (Studies 2 and 3) but also in the virtual reality of a computer-based task presented via the Internet (Study 1). Our findings are compatible with the view that a biological predisposition to preferentially process near or far space is a fundamental attribute of the visual systems of women and men respectively.

Of course it is possible that early childhood experiences serve to enhance any inherited predisposition for women to process visual information from near space better than that from far space and for men to show the reverse pattern. Indeed it is possible that these sex differences in visual processing are entirely the product of early experience with girls favoring near space activities while boys favor activities that emphasize far space. However, explanations that exclude a biological input are unlikely to be correct (see Halpern, 2000; Kimura, 1999). In fact, studies have found that partialing out sports history has little effect on the size of sex (Watson and Kimura, 1991) and sexual orientation (Hall and Kimura, 1995) differences in targeted throwing accuracy. In this light our findings may be seen as support for the view that present day sex differences in cognitive and motor performance are, at least in part, inherited and have their origins in our evolutionary past as encapsulated in the hunter-gatherer hypothesis.

A related prediction from the hunter-gatherer hypothesis concerns motor control. Selection for better control of the gross (proximal) muscles of the upper arm and shoulder would favor men as hunters by improving the accuracy of weapon throwing at prey. Similarly, selection for better control of the fine (distal) muscles of the wrist and fingers would favor women as gatherers by improving the accuracy of grasping target items. In a parallel paper (Sanders and Walsh, 2007) we have confirmed this motor control prediction in two separate studies. Using a computerized tracking task, with all tasks confined to near space to avoid near/far space confounds, we demonstrated that women performed better when they controlled the joystick with their hand (distal muscles) rather than their arm (proximal muscles) while men were better with their arm rather than with their hand. This sex difference in performance was seen with both the preferred and nonpreferred limbs and it was replicated in the second study.

Taken together the sex differences that we have demonstrated for motor control and visual processing are compatible with present day sex differences arising from a biological predisposition that we acquired via evolutionary selection during our hunter-gatherer past.

Neural sex differences

The reality of such sex differences as those we have demonstrated would be reinforced by the presence of separate underlying neural mechanisms for each of the behaviors. Separate mechanisms would provide neural bases for the differential development of male and female brains to support the sex-dimorphic behaviors. For motor control we found evidence in the literature for separate neural mechanisms controlling the distal hand and proximal arm muscles (Sanders and Walsh, 2007). Are there separate neural mechanisms for the visual processing of near and far space? We found evidence for such separate mechanisms in the clinical literature.

Studies of patients with radial visual neglect report a dissociation between far (extrapersonal) and near (peripersonal) space (Brouchon, Joanette, and Samson, 1986; Butler, Eskes, and Vandorpe, 2004; Halligan and Marshall, 1991; Vuilleumier, Valenza, Mayer, Reverdin, and Landis, 1998). An extension of those reports has come from three studies with normal human volunteers, one using transcranial magnetic stimulation (Bjoertomt, Cowey, and Walsh, 2002) and two using PET (Weiss et al., 2000; Weiss, Marshall, Zilles, and Fink, 2003), which confirmed that attending to, and acting in, far and near space draw differentially on two cortical pathways. The performance of tasks in far space is dependent on the ventral stream, from the primary visual cortex to the inferior temporal cortex, while the performance of tasks in near space is dependent on the dorsal stream, from the primary visual cortex to the posterior parietal cortex. On the basis of our behavioral findings we suggest that the dorsal "near" stream is favored in women and the ventral "far" stream in men.

Is there any evidence from brain studies that women and men make differential use of the dorsal and ventral streams as we have suggested? We have found one such study. Using fMRI, Gron, Wunderlich, Spitzer, Tomczak and Riepe (2000) have shown that searching for the way out of a virtual-reality maze differentially activated the right parietal and prefrontal cortex in women but the left hippocampus in men. This finding provides support for our view that women favor the near space processing dorsal stream while men favor the far space processing ventral stream.

Implications for the two visual systems

The visual neglect and other studies that we cited above have identified the ventral and dorsal cortical streams as visual systems for far and near space respectively. However, for some 25 years, a separate, widely accepted body of literature has traditionally identified the same two pathways as object identification and object localization systems, strikingly labeling the functions as the "what" and "where" processes of visual perception (Ungerleider and Mishkin, 1982). These functions were subsequently re-formulated as the visuoperceptual "what" and the visuomotor "how" processes of visual perception (Goodale and Milner, 1992). Neither model incorporated the far/near processing functions probably because the research on which they were based was conducted within near space. Clearly a further revision of the functions of the ventral and dorsal visual systems is required. At present we should note that in addition to their "what/where" or "what/how" roles, the ventral and dorsal cortical streams also have "there" and "here" visual processing functions and, in this respect, the two streams are sex-dimorphic, with the ventral "there" system interacting with far space and favored in men and the dorsal "here" system interacting with near space and favored in women. Future studies of the visual system should consider the potential impact of sex differences and the extrapersonal/ peripersonal spatial location of stimulus presentations.

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