

Research report

Sex differences in spatial memory using serial and search tasks

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HIGHLIGHTS

- Determined if sex influences the strategies employed during spatial navigation.
- Sex differences existed in those tests dependent on memory span.
- Sex differences were not observed in spatial organisational skills.
- Tests based on Euclidian and geocentric strategies did not reveal a sex difference.

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ABSTRACT

The present study assessed the spatial abilities of male and female human participants using different versions of the non-navigational Corsi block-tapping test (CBT) and a search task. Males performed significantly better than females on the standard manual version of the CBT; however, the standard CBT does not allow discrimination between spatial memory span and the role of spatial organisational factors (structure, path length and presence of crossings) in the sequences to recall. These organisational factors were assessed, therefore, in an experiment in which 7-block-sequences had to be recalled in a computerised version of the CBT. No sex differences in performance were observed on the computerised CBT, indicating that males do not make better use of spatial organisational principles. Accordingly, sex differences observed in the manual CBT are likely to rely upon differences in memory span between males and females. In the search task, participants could locate a goal by reference to a Euclidian space (the geometry of a virtual enclosure) or to proximal non-geometric cues. Both male and female participants showed a preference for the non-geometric cues, which overshadowed learning about the geometric cues when the two sets were available simultaneously during the training stage. These results indicate that sex differences do exist in those tests which are dependent on memory span. Sex differences were absent, however, in spatial organisational skills or in the usage of Euclidian and egocentric strategies to solve problems relying on spatial ability.

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1. Introduction

Sex differences in cognitive function have been reported since the early years of experimental psychology [12]. It is generally accepted, for example, that males show an advantage in spatial processing while females excel at verbal tasks [9,11,13,19]. Spatial learning refers to the ability of animals, including humans, to extract information from the environment to guide their navigation towards hidden goals. Keeping an accurate memory of the position and location of objects or places is an essential tool for animals to interact with their environment. Animals (at least mammals and birds with well-developed visual systems) can take advantage of

a number of information sources including, for example, the landmarks available in a particular environment [36], or the geometric cues that define specific locations in a shaped enclosure [7].

Biological differences between males and females mediate the processing of these sources of information. At a neuroanatomical level, multiple studies report larger brain volumes in men than women [1,8,31]. Also, relative to brain size, women have larger volumes in the hippocampus and the caudate nucleus [14,23], the anterior cingulate gyrus [29], the dorsolateral prefrontal cortex [40] and the planum temporale [42], whereas the relative volumes of amygdala and paracingulate gyrus are consistently larger in men [15,29]. At a neurochemical level, there are significant sex differences in the metabolism of multiple neurotransmitters and circulating sex hormone levels, which are known to modulate cognition [20,26,37]. At a physiological level, the hippocampus exhibits significant sexual dimorphism; for example, males show hippocampal LTP in response to both spaced and continuous tetanic

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stimulation, whereas in women the hippocampus only responds to continuous stimulation [43]; this difference seems to be mediated by circulating estrogen levels [16].

These biological differences might account for the sex differences in spatial abilities that have been traditionally reported [21]. However, a review of the literature suggests that males do not over perform females in all spatial tasks [2,33]. Spatial learning and memory is not a unitary function, but a multidimensional concept including discrete components [18]. Spatial tasks can differ in different ways, emphasizing for example the usage of distal rather than proximal landmarks and *vice versa*. Focusing on distal or proximal landmarks can activate different spatial strategies. Extensive research carried out over the last 40 years has shown that females generally favour an egocentric strategy which involves focusing on landmarks as directional cues, orienting themselves in terms of directions (right/left) which are relative to the self-position within the environment. In contrast, males favour an allocentric strategy, in which the agent uses the position of landmarks in relation to each other using a mental spatial map, or absolute directions (north/south), to navigate in the environment [2,24].

There is evidence for a favoured egocentric strategy in females and an allocentric strategy in males in navigational studies using non-human animals. In a recent study, Rodriguez et al. [38] trained male and female rats to find the location of an invisible platform in a Morris pool with two straight and one curved walls. The animals could locate the platform by reference to a geometric cue (the distinctive corner in which the straight walls of the pool met), or by reference to a discrete landmark situated over the distinctive corner (just above the edge of the platform). In a subsequent test, the landmark was moved to the centre of the curved wall so that the geometric and the landmark cues were put in conflict. Female rats spent most of the time during the test swimming near the discrete landmark, whereas males spent most of their time swimming in the distinctive corner. In a follow up study, Rodriguez and colleagues assessed how the two sources of information – geometric cues and the landmark – interact in female and male rats. After training with the geometry-landmark compound, the animals were tested in the presence of either the geometry or the landmark cue. It was found that in females the presence of the landmark hindered learning about the geometric cue but not the other way around, an instance of overshadowing [30] of the geometry by the landmark. In males, the opposite pattern was observed: the presence of geometric cues overshadowed the landmark but not the other way around [39]. Taken together, these results show that females preferentially process the proximal discrete landmarks, an egocentric strategy, whereas males preferentially rely upon the Euclidian space, an allocentric strategy. As discussed above, it is well established that males and females differ at neuroanatomical, neurochemical and physiological levels. It is important, therefore, to confirm in humans whether males and females show a preference for particular spatial strategies as a first step to ascertain what neuroanatomical, neurochemical and/or physiological factors are responsible for these strategy preferences. Hence, in the present study we addressed the relative preference for allocentric and egocentric strategies in human males and females.

In non-navigational spatial tasks, males have often been reported to show an advantage over females [13,41]. A popular task, frequently used in clinical and experimental settings, is the Corsi block-tapping test (CBT), a serial recall task which involves the integration of spatial and temporal information [3]. In the CBT, the experimenter taps on a number of irregularly distributed wooden blocks according to a particular sequence in the presence of the participant who is then required to repeat the sequence. The task starts with sequences involving a small number of blocks and gradually increases in difficulty by adding items in the

sequences, tapping up to nine blocks. The test can be used to measure both the number of tapping sequences correctly recalled and the longest sequence recalled. This last measure is often referred to as the block span, which averages about six for healthy human subjects [18]. In spite of the long-standing and widespread use of the CBT, there has been considerable inconsistency in virtually all aspects of task administration. The administration of the CBT can vary, for example, in terms of the tapping procedure, tapping rate, trials per level of sequence length (in terms of number of blocks tapped), the required order of recall (forward or backwards), or the way in which correctly recalled sequences are scored [3]. Furthermore, relatively simple tapping sequences with a clear spatial structure have been shown to be better recalled than complex sequences [4,17,28]. Using variations of the CBT basic task, inconsistent findings have been reported in relation to sex differences, with some studies reporting that males outperform females [25,32], and other studies reporting no sex differences [6,27]. One factor that seems to be modulating sex differences is the age of participants, with studies testing children aged 5–13 showing no sex differences, which tend to appear when testing participants aged 14 or above. This seems to suggest a larger short-term memory span that increases in males in the early adolescence period.

In light of these inconsistencies, the present study aimed to assess sex differences in humans using two spatial tasks, the non-navigational CBT which requires the integration of spatial and temporal information, and a navigation search task [34,35] which could be solved by reference to discrete landmarks or by reference to an Euclidian space—the geometry of a virtual enclosure. We used two versions of the CBT task. In order to produce normative data easily comparable with data from other studies, we first used a block tapping apparatus and administration technique adapted from original descriptions elsewhere [22]. We endeavoured to measure spatial span capacity comprehensively by administering several items at each level of difficulty, and we used item sequences that have been demonstrated elsewhere to be valid and reliable [5]. As we already discussed above, sex differences in the standard CBT can appear early in adolescence, i.e. in children aged 14 or above, presumably as a consequence of an increased memory span in males [27]. In the present study we will test young adults aged 18 or above, so we can expect males to outperform females in the standard CBT. Whether these differences are attributable to memory span or other factors that cannot be controlled for in the standard CBT task will be assessed by using a computerised version of the task. The computerised version of the test features square icons arranged as a square matrix presented on a touch screen [4]. In the computerised task a fixed number of elements will be present throughout the different experimental conditions to control for the influence of memory span in performance. This version of the Corsi test allows the manipulation of variables related to the type of sequence presented which have been shown to affect serial learning but the influence of which cannot be assessed using an irregular arrangement of wooden blocks. In particular we assessed the influence of variables related to the organisation of the to-be-recalled-sequence (see [4]), the length of the movement path required to select the blocks during recall and crossings in these paths (see [28] for a discussion of the role of these factors in spatial serial recall).

We also used two versions of the of the search task, one in which continuous geometry competed with the colour of the walls of a virtual enclosure, and one in which the geometry emerged from the spatial distribution of a number of landmarks (discontinuous geometry). In both cases we expected males to preferentially rely upon the geometric cues (which require an allocentric approach) whereas females should show a preference for the non-geometric cues (which require an egocentric approach).

2. Method

2.1. Participants

Two-hundred and four University of Leicester undergraduate students participated in this study in partial fulfilment of a course requirement. There were 101 males and 103 females (mean age 20.38; range 18–47). Participants had normal or corrected-to-normal vision. All subjects gave written informed consent in advance, and were informed about their right to withdraw from the research at any time.

2.2. Materials

2.2.1. Manual Corsi-block tapping test

The apparatus consisted of a fixed set of nine blue wooden blocks (3.0 × 3.0 × 3.0 cm) that were arranged irregularly on a 20.0 × 25.5 cm blue wooden board in accordance with the original Corsi display depicted in the work by Milner [22].

2.2.2. Computerised Corsi block tapping test

A PC equipped with a 19-in. touch-sensitive monitor was used to display the stimulus sequences and to collect the participant's responses. The stimuli were 2-D grey 4.0 × 4.0 cm square icons presented on a black background. There were 25 grey squares symmetrically organised in 5 rows per 5 columns. Individual squares could blink (they disappeared for 0.5 s) according to a pre-determined sequence. An E-prime (Psychology Software Tools Inc.) program controlled the presentation of different sequences and recorded the timing and the order in which icons were touched by the participants during recall.

2.2.3. Search task

A PC equipped with a 19-in. monitor was used to display the stimulus sequences and to collect the participant's responses; the computer was equipped with earphones. Throughout the experiment, the participants were required to use the mouse to click on action buttons in the screen. Two versions of the search task were used. In the first, the stimuli were a scalene triangle 17 cm in base and 11.2 cm in height, with internal angles of 85°, 60° and 35°; and a 12.5 cm sided equilateral triangle. The stimuli were presented in the centre of a black background in the computer screen, and could be outlined in white in some experimental stages, or with the three sides coloured in red, blue and purple in other experimental stages. In the second version, three landmarks were presented organized in such a way that the geometric cue—an isosceles triangle, 10.2 cm

in base and 15.5 cm in height, with internal angles of 70°, 70° and 40°—could emerge from their spatial distribution (discontinuous geometry). The landmarks could be distinctive, providing relevant information, or identical, in which case participants could only use the discontinuous geometry to sort out the location of the goal (see Table 1). Microsoft Office Power Point was used to control stimulus presentation and register the responses on an IBM-compatible PC; to do so, a number of macros were programmed using Microsoft Visual Basic that controlled the Power Point presentation and registered the participants' responses in a text file.

2.3. Procedure


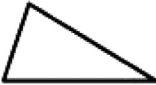
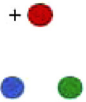
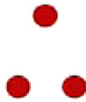

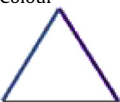
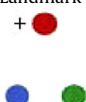

2.3.1. Manual Corsi block-tapping test

In the manual version of the CBT test the blocks were fixed to the board and were visible throughout the task. In each individual trial, the experimenter tapped a number of blocks at a rate of one block per second; the participant was then required to reproduce the tapping sequence. There were two sets of tapping sequences that have been demonstrated elsewhere to be reliable [5]; an equal number of participants was tested on each set of sequences. The sequences started off relatively short and simple with the use of three-block sequences, and then progressed to more difficult eight-block sequences. There were two sequences at each level of difficulty, and participants were required to recall at least one of the two sequences correctly in order to progress to the next level of difficulty.

2.3.2. Computerised Corsi block-tapping test

The computerised-CBT test required participants to observe a five by five grid of squares. At the onset of each trial, seven squares blinked (disappeared for 0.5 s) according to a predetermined sequence at a rate of one square per second. Thereafter, participants were required to reproduce the sequence by touching the squares using the touch screen monitor. The next sequence was not presented until seven squares were touched by the participant. The sequences varied in terms of structure, path-length (henceforth shortened to "Length") and path crossings (henceforth shortened to "Crossings"). These three variables have been shown to affect performance in computerised serial memory spatial tasks [4,17,28]. Structure refers to the relative location of each two squares to be touched in succession. If they were always located within the same row, column or diagonal, the sequence was structured (S); if they were located in different rows, lines or diagonals, the sequence was unstructured (U) (see [4] for a similar definition of organised sequences). Length refers to the total length of the movement

Table 1
Stimuli used in the assessment of the interaction between geometric and non-geometric cues. Only the groups trained with two cues and tested in the presence of one represented. Each condition had its own control, trained and tested with the same stimuli.

Training	Test	Training	Test
Replica 1: Continuous geometry and colour		Replica 2: Discontinuous geometry and landmarks	
Colour & C-Geometry ^a	C-Geometry	Landmark & D-Geometry ^b	D-Geometry
			
Colour and C-Geometry	Colour	Landmark & D-Geometry	Landmark
			

^a Continuous Geometry.
^b Discontinuous Geometry; + represents the rewarded location during training.

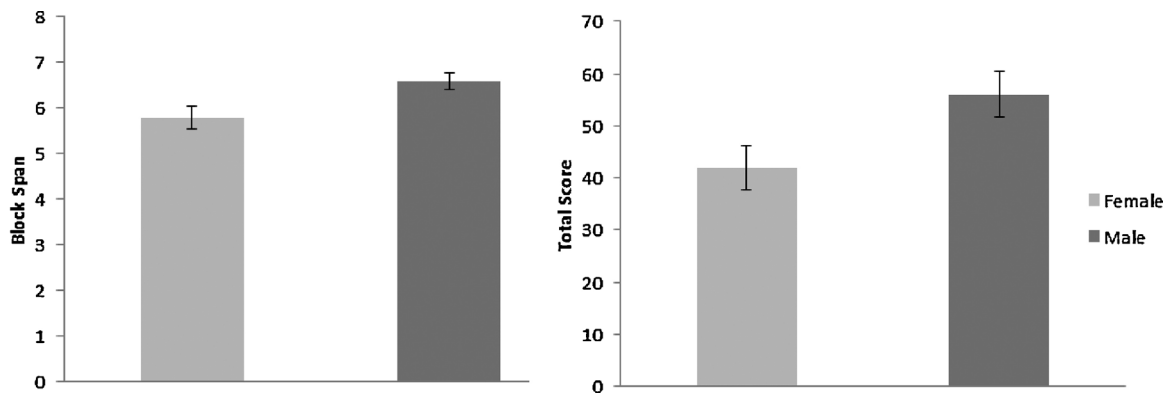


Fig. 1. Manual-CBT task: Accuracy of sequence reproduction (\pm SEM) for males and females. The block span is the length of the last correctly repeated sequence (left hand panel). The total score is the product of the block span and the number of correctly repeated trials before the test was discontinued (right hand panel).

required to reproduce the sequence by touching each of the icons in succession. Length was defined in terms of the number of squares that each line of the sequence bisected (see [28] for a similar definition). Long sequences (L) bisected a total of at least 10 items. Short sequences (S) bisected either four or five squares. Crossings refers to the presence or absence of crossings (if the path formed by successive locations crossed itself) within the sequence. Sequences with crossings (C) had at least three crossings. Sequences with no crossings (N) had none. We had therefore a factorial 2 (structure) \times 2 (length) \times 2 (crossings) design with eight different conditions defined by sequence type SLC, SLN, SSC, SSN, ULC, ULN, USC, and USN. There were eight trials per condition, which were randomly interspersed.

2.3.3. Search task

Once seated in front of the computer monitor, participants were provided with a set of instructions on the screen. The instructions informed the participants that they would be presented with images representing the plan of a room. There were different locations in the plan indicated by action buttons, and participants were informed that in one of those locations there was some food they had to recover to feed the three blind mice of the story. The task of the participants was simply to determine which of the alternative locations contained the food.

There were two phases in each of the experiments reported: place preference training and test. During the place preference training phase, all the participants were given forty-eight training trials in which they were asked to find the location of a goal in one of the vertices of one of the single shapes described in Section 2.2.3. Clicking on one of the action buttons was followed by auditory feedback indicating whether the choice was correct or not (a clapping sound indicated that the choice was correct whereas the sound of an explosion indicated a wrong choice); also, immediately after the response, the participants were shown a blank screen with a text box saying "Click here to continue"; participants had to click in this text box to proceed to the next training trial.

During the test phase of the experiment, all the participants were given sixteen test trials in which they were asked to identify the goal location by using either the original stimulus used during the place preference phase of the experiment, or a version of the stimulus containing part of the original information. The procedure for the test phase was identical to the one described for the place preference training but participants were not given feedback. Throughout all the phases of the experiments stimuli were rotated at random from trial to trial among eight possible orientations (0° , 45° , 90° , 135° , 180° , 225° , 270° , 315°) with the restriction that all the orientations had to be used in each block of eight trials.

3. Results and discussion

3.1. Manual Corsi block tapping test

Thirty participants (15 males and 15 females) were assessed using the manual CBT test, in which we registered the block span—number of blocks in the last successfully recalled sequence, as well as the total score—the product of the block span and the number of correctly recalled trials before the test was discontinued. Fig. 1 shows the performance on the manual-CBT task in terms of block span and total score. There was a significant difference between males ($M=6.60$, $SD=0.74$) and females ($M=5.80$, $SD=0.94$) on performance in terms of block span, $t_{28}=2.592$, $p<.05$, Cohen's $d=.95$. There was also a significant difference between males ($M=55.93$, $SD=16.96$) and females ($M=41.87$, $SD=16.15$) on performance in terms of total score, $t_{28}=2.326$, $p<.05$, Cohen's $d=.85$.

The present results show that the manual version of the CBT test, which involves the integration of spatial and temporal information contained in sequences presented on an irregular arrangement of blocks, elicited a male advantage in performance. Interpretation of this sex difference in performance is slightly difficult due to the inherent characteristics of the manual version of the CBT test where it is not possible to disentangle the role of organisational factors from that of memory span. In this test, the difficulty of the sequences is gradually augmented by increasing the number of blocks the participants have to recall. Several studies indicate that performance in serial recall tasks such as the Corsi test may result from a combination of memory span and organisational principles [4,10]. A computerised version of the Corsi test has been devised for f-MRI studies aimed at identifying the neural correlates of the organisational components of this task. In contrast with the irregular arrangement of items in the standard Corsi test, it features items arranged as a square matrix. With such a regular arrangement of items in rows and columns it is possible to manipulate the structure of the sequences so that structured sequences conform to the linear organisation of the display and unstructured sequences do not. A higher level of recall for structured sequences compared to unstructured sequences has been considered indicative of the use of organisational factors and associated with dorsolateral pre-frontal functions [4].

Moreover, the inherent features of the standard CBT test is that with the increase in the number of blocks tapped by the experimenter the sequences become increasingly complex, with longer path length and more likely to contain path-crossings. These are all factors that have been shown to affect performance in the CBT test [17,28], but cannot be effectively manipulated in the standard manual version with wooden blocks irregularly arranged on a board. If

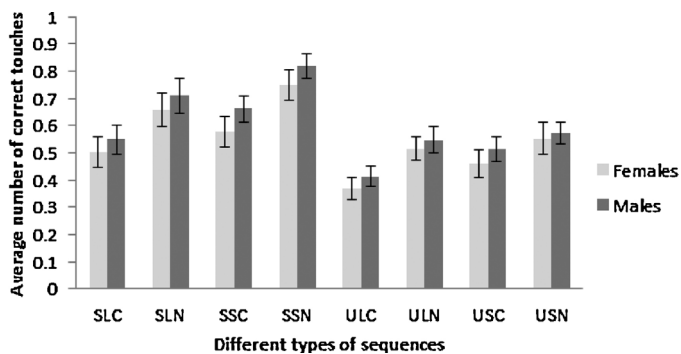


Fig. 2. Computerised-CBT task: Average proportion (\pm SEM) of correct touches for each type of test sequence for males and females. The three letters of each sequence refer to Structure (S=Structured; U=Unstructured); Length of Displacements (L=Long; S=Short); and Complexity (C=with crossings; N=no-crossings). For example, SLC refers to a structured, long and with crossings sequence.

males and females were differently affected by any of the factors discussed above, this could have determined a selective advantage in the standard Corsi test in the present experiment, independently or in addition to spatial span itself. We therefore used as second test where we determined whether this was the case by manipulating these variables in a computerised version of the CBT test.

Our second test was derived from that used by Bor et al. [4] in order to assess independently if organisational principles rather than memory span in itself determine the observed male advantage in spatial recall. If the male advantage observed in the present experiment was mainly determined by a better usage of organisational principles we should observe a selective advantage for structured sequences in male participants.

3.2. Computerised Corsi tapping block test

Thirty participants (15 males and 15 females, of which 9 males and 7 females were the same that were tested with the manual CBT test several weeks before) were assessed using the computerised CBT test. As described in Section 2.3.2, this task involved participants to reproduce, by touching the screen, sequences of blinking icons presented on a touch screen. The sequences varied in terms of whether they were structured or unstructured, required long or short path movements between successive blocks, and in the number of path crossings present (either three or none).

Fig. 2 depicts the proportion of correct touches for each test sequence for males and females. An ANOVA with sex (females vs. males), structure (structured vs. unstructured), path length (long vs. short) and crossings (with crossings vs. without crossings) showed a main effect of Structure, $F_{1,28} = 86.57$, $p < .01$, $\eta_p^2 = .75$, path-length, $F_{1,28} = 31.92$, $p < .01$, $\eta_p^2 = .53$, and crossings, $F_{1,28} = 82.03$, $p < .01$, $\eta_p^2 = .74$. The remaining factors (sex) and interactions were all non-significant, maximum $F_{1,28} = 4.16$.

The present results confirm that all the variables related to sequence type have an effect on spatial span, in accordance with the literature [4,17,28]. Nevertheless the absence of sex differences and interactions confirmed that males and females were affected in the same way by these variables. Taken together, the results of the manual and the computerised CBT tests indicate that sex differences appear to be related to memory span itself and not mediated by a differential use of organisational factors or by a different influence of factors related to sequence type in the two sexes.

3.3. Geometry learning

Thirty participants (15 males and 15 females, the same participants that were assessed on the manual CBT test; the order of

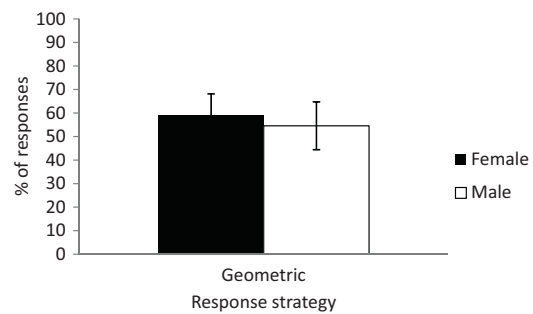


Fig. 3. Geometry learning: Mean percentage (\pm SEM) of geometry responses during the test phase of the experiment.

presentation of the tests was counterbalanced across participants) were assessed using the search task. Male and female participants were trained with a geometry–colour compound (a scalene triangle with coloured sides) and tested in the presence of the geometric cue alone (the scalene triangle outlined in white). During the training phase of the task all the participants learnt the location of the goal. The percentage of correct responses of the female participants during the first block of 16 trials was 82.91 (3.52); during the second and the third blocks of trials the percentage of correct responses were 100 (0) and 100 (0), respectively. The percentage of correct responses for the male participants in the three blocks of trials were 84.16 (2.50), 98.75 (0.66) and 100 (0). An ANOVA with sex (Female vs. Male) and blocks of trials as factors showed a significant effect of blocks of trials, $F_{2,56} = 54.13$, $p < .01$, $\eta_p^2 = .66$. Neither the sex factor nor the sex \times blocks of trials interaction was significant, $F < 1$.

Fig. 3 shows the mean percentage of correct responses for females and males for the geometry response strategy during the test phase of the experiment—in which participants were required to locate the goal by using the geometric cues. A one-way ANOVA with sex (female vs. male) as the factor showed that females and males did not differ in the percentage of the correct responses $F < 1$. One sample T -tests showed that the percentage of correct responses observed was above chance level for Females, $t_{14} = 2.91$, $p < .05$; this difference was marginally significant for male participants, $t_{14} = 1.98$, $p = .06$.

The search task, which required participants to locate a goal by reference to a Euclidian space during the test – the geometry of the virtual enclosure – did not elicit a sex difference. Females were expected to show a poorer performance than males in the Euclidian space, an outcome that has been frequently reported in the literature. However, the design of the present experiment did not assess performance of participants in the presence of the proximal cues (the coloured sides of the virtual enclosure), a task in which females could be expected to outperform males. This was assessed in the next experiment, in which after training with the geometry–colour compound, males and females were assessed in the presence of the two cues in conflict, to see whether males showed a preference for the geometric cues and females a preference for the proximal colour cues.

3.4. Geometry and proximal learning

Thirty participants (15 males and 15 females, the same that were assessed in the computerised CBT test; the order of presentation of the tests was counterbalanced across participants) were assessed using the search task. As in the previous experiment, both geometric and colour cues could assist performance in finding the hidden food during the training phase of the experiment. In contrast with the previous experiment, in the present task the geometric and the colour cues were presented in conflict during the test phase,

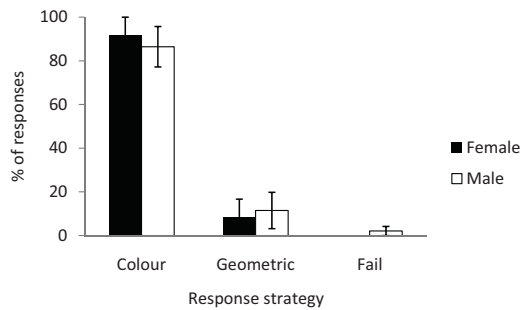


Fig. 4. Geometry and proximal learning: Mean percentage (\pm SEM) of colour, geometry and fail responses during the test phase of the experiment.

allowing us to assess whether males and females show a differential preference for geometric and colour cues.

During the training phase of the search task all the participants learnt the location of the goal. The percentage of correct responses of the female participants during the first block of 16 trials was 82.29 ($SEM = 6.19$); during the second and the third blocks of trials the percentage of correct responses were 100 (0) and 98.85 (0.70), respectively. The percentage of correct responses for the male participants in the three blocks of trials were 76.04 (7.57); 91.14 (5.51) and 97.39 (2.60). An ANOVA with sex (female vs. male) and blocks of trials as factors showed a significant effect of blocks of trials, $F_{2,44} = 14.55$, $p < .01$, $\eta_p^2 = .39$. Neither the sex factor nor the sex \times blocks of trials interaction was significant, $F_s < 1$.

Fig. 4 shows the mean percentage of correct responses for females and males for the three response strategies: colour, geometry and fail during the test phase of the experiment—in which participants were given a choice between the geometry and the colour cues (presented in conflict). Both females and males showed a strong preference for the colour strategy. Three one-way ANOVAs with sex (female vs. male) as the factor showed that females and males did not differ in the percentage of responses in any of the three strategies, maximum $F_{2,44} = 1.00$.

In the present experiment, both female and male participants showed a clear preference for the colour cue when the elements of the compound were put in conflict during the test—in contrast with previous studies using rats [38] which have shown that males preferentially use the geometry of an enclosure (Euclidian space) whereas females tend to show a preference for the landmarks (a proximal strategy). The present results seem to suggest that the colour cue was more salient than the geometric cue, attracting the attention of all the participants that ignored the geometric cue in favour of the colour during the test. The previous experiment (see Section 3.3), however, clearly showed that both females and males could use the geometric cue at levels above chance after training with a geometric-colour compound. The design of the present experiment might have not been sensitive to sex differences with the set of stimuli used. With equally salient geometric and colour (or landmark) cues females and males could show a differential pattern: males would show better processing of the geometric cue at the expense of the colour (or landmark) cue whereas females might show a better preference of the colour cue at the expense of the geometric cue. We assessed this possibility (see below, Section 3.5) by using the same stimuli employed here, and a different set of stimuli designed to minimise the differences in salience between the proximal and the geometric cues.

3.5. Interaction between geometric and non-geometric cues

One hundred and sixty participants (80 males and 80 females) were assessed using the search task to assess sex differences in the way in which geometric and non-geometric cues interact. There

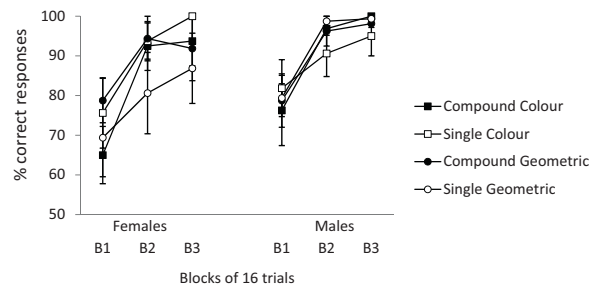


Fig. 5. Interaction between continuous geometry and colour cues: Training. Mean percentage (\pm SEM) of correct responses across blocks of 16 training trials for the different experimental groups by sex.

were two replications of this experiment. The first one used the stimuli used in the previous experiments. In the second replication the colour cue was replaced by a set of distinctive landmarks, and the continuous geometry of the virtual enclosure used in previous experiments was replaced by a discontinuous geometric cue—in which the geometry emerged from the spatial distribution of the landmarks (see Table 1).

Males and females were compared across four experimental conditions. In the compound groups, participants were trained in the search task in the presence of a proximal cue (colour in replication 1; landmarks in replication 2) and a geometric cue (continuous in replication 1; discontinuous in replication 2). Following training, half the participants in the Compound condition were tested in the presence of the proximal cue (compound-proximal group) whereas the other half was tested in the presence of the geometric cue (compound-geometric group). In the Single groups, participants were trained and tested in the presence of either the proximal or the geometric cue—the same cue was used for training and test (single-proximal and single-geometric groups).

If females and males have preference for proximal and geometric cues respectively, we could expect a differential pattern of results by sex. In females, the proximal cues could better interfere with the processing of the geometric cues; therefore, overshadowing of the geometric by the proximal cues should be observed, but not the other way around. On the other hand, if males preferentially process the geometric cues, overshadowing of the proximal by the geometric cues should be observed, but not the other way around [39].

3.5.1. Interaction between continuous geometry and colour

Fig. 5 shows the mean percentage of correct responses for Females and Males across the three blocks of 16 training trials. All the participants readily learnt the location of the goal. An ANOVA with sex (Female vs. Male), training (Compound vs. Single), cue (geometry vs. colour) and blocks of trials as factors showed a significant effect of blocks of trials, $F_{2,144} = 78.55$, $p < .01$, $\eta_p^2 = .52$. None of the other factors and interactions were significant, maximum $F_{2,144} = 2.28$.

Fig. 6 shows the mean percentage of correct responses for the groups overshadowing and control, for females and males, in the groups tested with the geometric and the colour cues. An ANOVA with sex (female vs. male), training (compound vs. single), cue (geometry vs. colour) as the factor showed a significant effect of training, $F_{1,72} = 16.83$, $p < .01$, $\eta_p^2 = .18$, cue, $F_{1,72} = 9.97$, $p < .01$, $\eta_p^2 = .12$, and a significant Training \times Cue interaction, $F_{1,72} = 11.12$, $p < .01$, $\eta_p^2 = .13$. All the remaining factors and interactions were non-significant, maximum $F_{1,72} = 1.46$. Further analyses carried out to analyse the training \times cue interaction, simple main effects, showed that groups overshadowing and control significantly differed in the groups tested with the geometric cue, $F_{1,39} = 11.95$, $p < .01$, $\eta_p^2 = .23$; there were no differences, however, between the

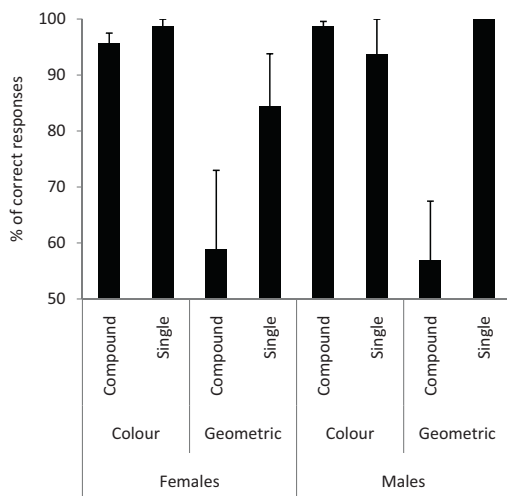


Fig. 6. Interaction between continuous geometry and colour cues: Test. Mean percentage (\pm SEM) of correct responses for females and males, for participants tested in the presence of the colour and the geometric cues, and trained with a compound cue (compound) or in the presence of a single cue (single).

overshadowing and control groups in the groups tested with the colour cue, $F < 1$.

3.5.2. Interaction between discontinuous geometry and landmarks

Fig. 7 shows the mean percentage of correct responses for Females and Males across the three blocks of sixteen training trials. An ANOVA with sex (female vs. male), training (compound vs. single), cue (geometry vs. colour) and blocks of trials as factors showed a significant effect of sex, $F_{1,72} = 5.92$, $p < .05$, $\eta_p^2 = .08$, cue, $F_{1,72} = 4.61$, $p < .05$, $\eta_p^2 = .06$ and blocks of trials, $F_{2,144} = 69.80$, $p < .01$, $\eta_p^2 = .49$. The following interactions were also significant: blocks of trials \times sex interaction, $F_{2,144} = 7.29$, $p < .01$, $\eta_p^2 = .09$; blocks of trials \times cue, $F_{2,144} = 4.33$, $p < .05$, $\eta_p^2 = .06$; block of trials \times sex \times training, $F_{2,144} = 4.65$, $p < .05$, $\eta_p^2 = .06$; and the blocks of trials \times sex \times training \times cue, $F_{2,144} = 3.20$, $p < .05$, $\eta_p^2 = .09$. The remaining factors and interactions were all non-significant, maximum $F_{1,72} = 3.20$.

Further analyses were carried out to analyse the blocks of trials \times sex \times training interaction. Three ANOVAs with sex and training as the factors were performed on the data of each block of training trials. In Block 1, the factor sex was significant, $F_{1,76} = 6.80$, $p < .05$, $\eta_p^2 = .08$, as well as the sex \times training interaction, $F_{1,76} = 4.27$, $p < .05$, $\eta_p^2 = .05$. Further analyses, simple main effects, carried out to further analyse this interaction showed that the training

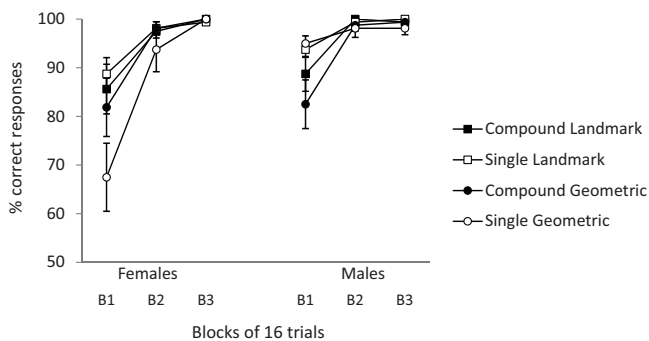


Fig. 7. Interaction between discontinuous geometry and landmarks: Training. Mean percentage (\pm SEM) of correct responses across blocks of 16 training trials for the different experimental groups by sex.

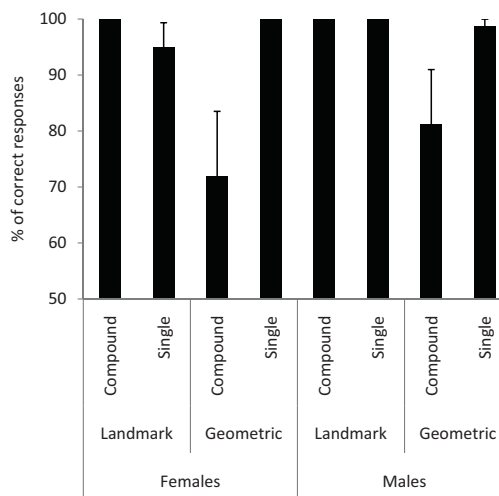


Fig. 8. Interaction between discontinuous geometry and landmarks: Test. Mean percentage (\pm SEM) of correct responses for females and males, for participants tested in the presence of the landmark and the geometric cues, and trained with a compound cue (compound) or in the presence of a single cue (single).

(compound vs. single) was not significant for the females; for the males, however, there was a significant effect of training, with the males showing slower learning in the presence of the compound cues (geometry + landmark) than in the presence of single cues (either geometry or landmark), $F_{1,38} = 7.44$, $p < .05$. In blocks 2 and 3, the ANOVAs showed no significant effects, $F < 1$.

Additional analyses were carried out to analyse the four factors interaction blocks of trials \times sex \times training \times cue interaction. Three ANOVAs with sex, training and cue as factors were performed on the data of each of the three blocks of trials. In block 1, the factors sex, $F_{1,72} = 7.47$, $p < .01$, $\eta_p^2 = .09$, and cue, $F_{1,72} = 5.12$, $p < .05$, $\eta_p^2 = .06$, were significant. There was also a significant sex \times training interaction (already analysed above), $F_{1,72} = 4.70$, $p < .05$, $\eta_p^2 = .06$, and a marginally significant sex \times training \times cue interaction, $F_{1,72} = 3.55$, $p = .06$, $\eta_p^2 = .05$. Additional analyses were carried out to analyse the triple interaction. Two ANOVAs with sex and cue as factors were carried out on the data of the compound and single training. In the groups given compound conditioning, the analysis did not reveal any significant effects. In the groups given single training, however, the factor sex, $F_{1,39} = 13.76$, $p < .01$, $\eta_p^2 = .27$, and cue, $F_{1,39} = 5.21$, $p < .05$, $\eta_p^2 = .12$ were significant. There was a significant sex \times cue interaction, $F_{1,39} = 6.59$, $p < .05$, $F_{1,39} = 6.59$, $p < .05$, $\eta_p^2 = .15$. The analysis of the simple main effects showed that for males, the participants trained with geometry and landmark did not differ. In contrast, females trained in the presence of the geometry cue learned slower than females trained in the presence of the landmark cues, $F_{1,19} = 6.29$, $p < .05$.

Fig. 8 shows the mean percentage of correct responses for the groups overshadowing and control, for females and males, in the groups tested with the geometric and the colour cues. An ANOVA with sex (female vs. male), training (compound vs. single), cue (geometry vs. landmark) as the factor showed a significant effect of training, $F_{1,72} = 6.58$, $p < .05$, $\eta_p^2 = .08$, Cue, $F_{1,72} = 7.41$, $p < .01$, $\eta_p^2 = .09$, and a significant training \times cue interaction, $F_{1,72} = 10.22$, $p < .01$, $\eta_p^2 = .12$. All the remaining factors and interactions were non-significant. Further analyses carried out to analyse the training \times cue interaction, simple main effects, showed that groups overshadowing and control significantly differed in the groups tested with the geometric cue, $F_{1,39} = 9.28$, $p < .01$; there were no differences, however, between the overshadowing and control groups in the groups tested with the landmark cue.

3.5.3. Discussion

The results of the present experiment show that proximal cues tend to overshadow learning about geometric cues (and not the other way around) both in females and males. This pattern of results suggests that proximal cues are more salient than geometric cues, attracting the attention of the participants at the expense of the geometric cues. The good performance showed by the groups single (trained and tested with either proximal or geometric cues) demonstrate that all the cues employed in the present experiments can gain control over the choices of the participants when presented in isolation.

It is worth considering the training phase of the two replicas. In both experiments, females showed a slower learning of the geometric cue than males (groups single-geometric). Although in the experiment assessing continuous geometry and colour this difference was not statistically significant, when these cues were substituted by discontinuous geometry and landmarks (see Fig. 7) the difference became significant. This seems to confirm that males have a better ability for exploiting the Euclidean spaces than females. We did not observe slowed learning of the proximal cue in males, probably due to the relatively high salience of the proximal cues employed in the present experiments.

4. Conclusions

The results reported provide important original results regarding sex differences in spatial memory. Male participants tested on the standard Corsi test showed a better performance – in terms of block span and total score – than female participants. These sex differences replicate the result previously reported in some studies using the standard version of the Corsi test [25,32]. Sex differences in the standard Corsi test could be attributed to the role played by organisational factors or by differences in the memory span between males and females. The problem with the standard version of the Corsi test is that it does not allow assessment of the organizational factors. We therefore used a computerised version of the test that allowed the systematic manipulation of variables associated with the use of organisational factor and path characteristics of the to-be-reported sequences while assessing recall of seven block sequences in male and female participants. The results showed that both males and females recalled better structured than unstructured sequences; sequences with short displacements better than sequences with long displacements between consecutive blocks; and sequences in which there were no crossings better than sequences with path crossings. The absence of sex differences in the computerised Corsi test strongly suggests that the differences observed in the standard Corsi test are unlikely to be an expression of differences in spatial organisational abilities between males and females, and are more likely to be related to memory span per se.

Male and female participants were also assessed on their ability to exploit different sources of information in a search task. Previous research in rats has shown that males favour an allocentric

strategy – usage of a Euclidian space or cognitive map – whereas females tend to favour the usage of an egocentric strategy—usage of discrete landmarks [38,39]. In the present experiments, male and female human participants were trained in a search task in which the location of a goal could be inferred by using geometric cues – the boundaries of a virtual enclosure – which require an allocentric strategy, or discrete cues – the colour of the walls of the virtual enclosure or distinctive landmarks – which require the usage of an egocentric strategy. After training with the geometry–colour compound, both males and females proficiently used the geometric cue to locate the goal during the test; interestingly, when the two sources of information were put in conflict, both males and females showed a clear preference for the colour cue. These results suggest that although the participants can use both sources of information, the colour cue is more salient and hence tend to control the search behaviour of both males and females. Subsequent experiments assessed how the geometric and the non-geometric (colour of the walls of the enclosure, or discrete landmarks) cues interact. It was found that non-geometric cues overshadow learning about the geometric cues but not the other way around both in males and females. However, when the participants were trained in the presence of geometric and non-geometric cues in isolation (control groups), we observed a deficit in learning about the geometric cues in females; in contrast, male participants showed a similar learning rate with geometric and non-geometric cues. This might be taken to be evidence for an advantage in the usage of Euclidian spaces in males. We did not observe, however, an advantage of females in the processing of non-geometric cues that require an allocentric strategy—perhaps due to the high salience of the non-geometric cues used in the present experiments. The task used in the present experiments seems to contain highly salient non-geometrical information that can be effectively used by males and females, hindering any chances of sex differences to be observed. In that respect, the present results seem to be in agreement with the literature in that sex differences are likely to be observed when landmark information is sparse and navigation must be performed using a Euclidian strategy (as is the case in the group Single-Geometric, in which females showed a significant deficit), and decreased when salient landmark information is available favouring an egocentric strategy [2].

To conclude, the present study indicates that sex differences do exist in tests which are dependent on memory span. However, sex differences are absent, or at least very weak, in humans, in those tasks that require spatial organisational skills and tasks that require the usage of Euclidian and egocentric strategies to solve problems utilising spatial abilities.

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Appendix A.**Corsi Block-Tapping Test (CBT) Instructions****Manual Corsi Block-Tapping Test**

Tester: “I will touch the wooden blocks according to a particular sequence; your task is to repeat the sequence by touching the blocks in the same order without delay”.

Computerised Corsi Block-Tapping Test

You will be presented with an array of square icons on the screen which would blink according to a particular sequence. Your task is to repeat the sequence by touching the icons on the screen in the same order without delay.

Appendix B.**Search Task Instructions****Training**

In the present experiment you will be asked to help three blind mice to get some food. The mice have been living in a kind lady’s house, who used to leave some cheese for them in one corner of the kitchen every day. They were very happy days... But now the nephew of that lady has come to stay for a few weeks. He hates mice, and secretly put some mice traps in the other corners of the kitchen.

The three blind mice are terrified because they cannot get to the food safely. So they have asked for help from the Organization “Save the Mice”. We are trying to recruit volunteers to help the three blind mice.

Through a series of trials you will be trained to recover the food from the kitchen using a simulator. Although it seems to be a simple task, it isn’t that easy. You will need to explore the kitchen during the night, so it will be dark. However, some cues will help you to identify the correct corner, where the food is hiding. Be very careful... A mistake and you will get trapped!!!

During the training you will be shown a plan of the kitchen. Your task is to determine which is the corner where the food is hiding. In every corner you will find an icon. Clicking one of those icons will activate an auditory cue that would indicate whether your choice was the correct one or not.

Click the icon below to see how you will be informed of a correct choice (clicking is followed by a clapping sound).

Click the icon below to see how you will be informed of an incorrect choice (clicking is followed by an explosion sound).

Now you will be presented with the real problem. The plan of the kitchen will be rotated in every trial, and you will only be allowed one choice within each trial. At the start of this task you will be unaware of which response is correct so you might get trapped quite frequently during the first few trials. However, the feedback provided by the computer will allow you to learn the correct corner where the food is hiding.

Get ready. Your training as a volunteer for Save the Mice is about to start

Test

Now you have completed the first part of your training. Save the Mice is very grateful for the efforts you have made to become a good food retriever.

To complete your training you need to show how good you are at retrieving the food for our mice: In this phase there will be no auditory signals!

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