Gender Differences in Navigational Memory: Pilots vs. Nonpilots

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INTRODUCTION: The coding of space as near and far is not only determined by arm-reaching distance, but is also dependent on how the brain represents the extension of the body space. Recent reports suggest that the dissociation between reaching and navigational space is not limited to perception and action but also involves memory systems. It has been reported that gender differences emerged only in adverse learning conditions that required strong spatial ability.

METHODS: In this study we investigated navigational versus reaching memory in air force pilots and a control group without flight experience. We took into account temporal duration (working memory and long-term memory) and focused on working memory, which is considered critical in the gender differences literature.

RESULTS: We found no gender effects or flight hour effects in pilots but observed gender effects in working memory (but not in learning and delayed recall) in the nonpilot population (Women's mean = 5.33; SD= 0.90; Men's mean = 5.54; SD= 0.90). We also observed a difference between pilots and nonpilots in the maintenance of on-line reaching information: pilots (mean = 5.85; SD=0.76) were more efficient than nonpilots (mean = 5.21; SD=0.83) and managed this type of information similarly to that concerning navigational space. In the navigational learning phase they also showed better navigational memory (mean = 137.83; SD=5.81) than nonpilots (mean = 126.96; SD=15.81) and were significantly more proficient than the latter group.

DISCUSSION: There is no gender difference in a population of pilots in terms of navigational abilities, while it emerges in a control group without flight experience. We found also that pilots performed better than nonpilots. This study suggests that once selected, male and female pilots do not differ from each other in visuo-spatial abilities and spatial navigation.

KEYWORDS: sex differences, spatial orientation, human navigation, visuo-spatial memory, aircrew, spatial cognition.

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The coding of space as near and far is not only determined by arm-reaching distance, but is also dependent on how the brain represents the extension of the body space. Near space refers to the portion of space within "grasping distance" (i.e., the space in which a seated individual can grasp an object), whereas far space, also called navigational space,[9] extends beyond our reach and has been called the space within "walking distance".[13] The space around us is a multifactorial construct of our brain and distinct areas are responsible for coding space behaviorally defined as outside reaching distance (far space), and as within reaching distance (near space).[3,35] The first distinction between grasping and walking distance was proposed by Brain.[6] He suggested that different neural representations exist for near and far distances due to the perceptual and motor systems which mediate responses to external stimuli. Indeed, the relevance of actions performed by others may be different depending on the regions of space in which they are executed and they can lead to different behavioral responses. It is reasonable to hypothesize that visuo-spatial memory can be organized with respect to near and far elements as well as with respect to purposes (object-location vs. environmental navigation).[15,27] Recently, the hypothesis was advanced that the

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dissociation between reaching space and navigational space might be not limited to perception and action, but might extend to memory systems.[21,32,34] Deficits of short- and long-term memory, which are selective for stimuli in reaching or navigational space, have been reported following surgical resection of the medial temporal lobes or following unilateral cerebral vascular accidents in patients, as well as in healthy subjects suffering from selective navigational disorders.[4,30,32] The presence of double dissociation between the two spatial domains suggests the existence of independent memory processing of visuo-spatial information in reaching and navigational space that may consist of two independent or partially overlapping systems. Specifically, in cognitive science a "double dissociation" is the demonstration that two experimental manipulations have different effects on two dependent variables (e.g., if a lesion in brain structure A impairs function X but not Y, and a lesion to brain structure B impairs function Y but spares function X, one can make more specific inferences about brain function and function localization). In a recent fMRI study, Nemmi et al.[21] demonstrated that coding, storing, and processes for retrieving visuo-spatial information in reaching space are subserved by neural systems that differ from those subserving coding, storing, and retrieval in navigational space. Indeed, these authors found that the networks of the right lingual gyrus, calcarine sulcus, and dorsolateral prefrontal cortex are specifically associated with learning in navigational space, while the left inferior temporal gyrus, lingual, fusiform gyrus, and middle occipital gyrus are associated with learning sequences in reaching space. Their results suggest that a partial segregation may exist between neural circuits for reaching and navigational space not only in the domains of perception and action planning but also in memory.

Navigational memory refers to a specific memory system devoted to storing paths[28,34] and flexible mental representations of familiar and new environments referred to as cognitive maps.[25,39] These mental representations encompass the spatial layout of an environment from a survey perspective and include the positions of landmarks, as memorized by the individual, relative to other landmarks as well as distances and orientations. These cognitive maps allow people to use a shorter path and reach unseen known goal locations regardless of their position in the environment (allocentric spatial coordinates). Differently, when people use their own position to decide their next navigational step they are navigating by means of egocentric spatial coordinates. Both allocentric and egocentric strategies coexist during movement in the environment. Similarly, a landmark may have both an allocentric location (e.g., Milan is located north of Naples) and an egocentric location (e.g., Cagliari is located to the left of north while facing Milan). Good navigators seem to be those who are able to switch from one reference frame to another, depending on what is the best in a given situation.

Gender differences in navigation have been described for the different types of strategies used by women and men to move through the environment. Landmark-based strategies are preferred by women and Euclidean-based strategies (e.g., geometric shapes of the environment) by men.[11,36] Moreover, it is known that men outperform women when they have to learn routes on a map both in the real world and in a virtual environment.[1,38] Piccardi et al.[31] found that gender differences emerged only in adverse learning conditions that required strong spatial ability, while they decreased when participants were allowed to take their time or to repeat the task as many times as needed. This suggests that interactions between environmental demands and cognitive processes modulate gender differences. In general, gender differences seem to emerge in the learning phase of navigational memory and can be determined by differences in the use of strategies.[29] However, in expert populations such as military pilots, gender differences are not present and men and women show the same level of proficiency.[40] Pilots' proficiency seems to be related to flight experience. Indeed, expert pilots have greater experience than novel pilots in dealing with many different inputs that require interoperable working memory and attention, such as managing the visual data of speed and direction in order to maintain the ideal flight path.[16,26]

Based on these considerations, the aim of the present study was to determine whether there were gender differences in a group of experienced pilots compared with a group of nonpilots both in reaching and/or navigational memory. The null hypothesis was that no gender differences exist in terms of navigational memory in these populations. For this purpose, we used two popular experimental and clinical tools: the Corsi Block-Tapping test (CBT)[37] to investigate reaching memory, and the Walking Corsi Test (WalCT)[28,34] to investigate navigational memory. The CBT[37] is a test largely employed by clinical neuropsychologists as well as developmental and cognitive psychologists to assess visuo-spatial memory and the WalCT[34] is a test to investigate navigational memory employed as above in experimental settings and in clinical practice.

We assessed participants' performance with regard to temporal duration (working memory and long-term memory) by focusing on the learning phase, which is considered crucial in the gender differences literature.

METHODS

Subjects

We investigated 41 pilots (20 men and 21 women) and 28 nonpilots (14 men and 14 women). The pilots were students of the Italian Air Force Academy who were in the final stage of the training course or just assigned to the operational units. These latter had flight experience on the following aircraft: C-130, Falcon 50, G-222, and P-180 Avanti. The recruitment included all female pilots in the Italian Air Force at the time of the study. Pilots were also stratified for flight experience [mean flight hours: men 426.45 $\pm$ 324.68 and women 409.67 $\pm$ 324.68; $T(1,40)=0.38$; $P = 0.70$] due to different stages of the flight training. Nonpilots were college students with no flight experience. They were matched with the pilots for age, sex, cultural level (i.e., third year of University or with basic degree). Only right handed subjects were included in both groups, all with no history of neurological or psychiatric disease. The protocol met the criteria of the Declaration of Helsinki and was approved in advance by the Institutional Ethical Board. All subjects signed an informed consent document before entering the study and undergoing the protocol, which did not include any invasive procedures. Subjects were grouped for the analysis as pilots and nonpilots; demographic details are provided in **Table I**.

Instruments

The Corsi Block-Tapping Test (CBT). The CBT is a performance-based test that takes 30 min to be completed and was developed by Corsi in 1972. It has been used for several purposes, including the assessment of deficits in immediate nonverbal memory, investigating gender differences in spatial skills, for clarifying theoretical conceptions of visuo-spatial memory[2] and more recently as comparison with WalCT to highlight different type of visuo-spatial memory, one more devoted to assess reaching space by means of CBT and the other one to test navigational memory through WalCT.[21,27–34] From its development, CBT was also used in several clinical populations, including Korsakoff's patients, demented individuals (e.g., with Alzheimer's or Huntington's disease), several neurological disorders,[2] as well as in learning-disabled children and the mentally retarded (among them, Downs syndrome and Williams syndrome). The CBT consists of nine blocks (4.5 × 4.5 cm) fixed on a board (30 × 25 cm) in a scattered array (**Fig. 1A**).

The Walking Corsi Test. The Walking Corsi Test (WalCT) is a larger version of the CBT (3 × 2.5 m; scale 1:10 of the CBT) set up in an empty room. It was developed by Piccardi and coworkers in 2008 and has been demonstrated to be able to measure navigational memory, allowing detection of navigational disorders both in clinical and in healthy populations.[27,34] Also, in this case the clinical population included neurological disorders (such as stroke, Alzheimers, drug-resistant epilepsy patients),[5,30,32] and it has been used for investigating gender differences and ageing effects.[30,34] It takes around 30 min and requires the same experimental conditions as CBT. In this test, the subject has to actually walk and reach different locations. The WalCT consists of nine squares placed on a carpet in the same position as in the standard CBT (**Fig. 1B**).

Procedure

Subjects were first submitted to the CBT and the WalCT, which assess span, learning, and delayed recall. Visuo-spatial short- and long-term memory were both tested. In the visuo-spatial short-term memory task (VS-TM) the experimenter taps a number of blocks at a rate of one block per 2 s, after which the participant has to tap the block sequence in the same order it was presented. The block sequences gradually increase in length (starting from a 2-block sequence) and the score is the number of blocks in the longest sequence remembered correctly (block span). Two aspects of visuo-spatial long-term memory were assessed: learning (VS-L) and delayed recall (VS-DR). In VS-L, subjects had to learn an eight-block sequence presented by the examiner, according to a previously described protocol.[37] The learning criterion was reached if the subject reproduced the correct sequence three times in a row (max number of trials: 18). The learning score was calculated by attributing one point for each block correctly tapped until the criterion was reached; then it was added to the score corresponding to correct performance of the remaining trials (up to the 18th; maximum score:144). The VS-DR was administered 5 min later. The examiner asked the participant to reproduce the previously learned eight-block sequence. Scores were calculated on the basis of the number of blocks correctly reproduced. Participants were tested individually in a quiet room with artificial lighting. They were seated facing the examiner on a height-adjustable office chair in front of the CBT board.

The same experimental conditions were adopted in the WalCT as in the CBT except for that the starting position was different. In the WalCT both the examiner and the participants started from the same point. To avoid different points of view influencing performance on the WalCT, the location of the starting position was decided in advance. This was done to facilitate replication of the test in rooms that are larger than the carpet. The experimenter illustrated the sequence by walking on the carpet and stopping on each square for 2 s. Then the subjects had to repeat the same sequence as the experimenter by walking and stopping on the squares included in the sequence. Participants performed three different tasks: Topographical Short-term Memory (TSTM), in which a square span was obtained; Topographical Learning (TL), in which participants were asked to learn an eight-square sequence following the same procedure and adopting the same learning criterion as in the CBT; and Topographical Delayed Recall (TDR), in which participants have to show the eight-square sequence 5 min later. A modified version of the TL task was proposed in which participants had to learn a 13-square sequence. The aim was to increase the difficulty to elicit the presence of gender effects in the pilot population. The procedure and the learning criterion was the same as that of the CBT and

Table I. Demographic Data: Mean and Standard Deviations (SD) in Parenthesis.

GROUPS	AGE (YR)	EDUCATION (YR)	FLIGHT HOURS
Male Pilots (N = 20)	25.95 (3.41)	16.70 (1.92)	426.45 (324.68)
Female Pilots (N = 20)	26.95 (4.04)	17.57 (0.87)	409.67 (324.68)
	T = 0.52; P = 0.61 (n.s.)	T = 1.89; P = 0.07 (n.s.)	T = 0.38; P = 0.70 (n.s.)
Male Nonpilots (N = 13)	25.23 (3.90)	13.46 (2.22)	—-
Female Nonpilots (N = 15)	23.67 (2.85)	14.80 (2.24)	—-
	T = 1.22; P = 0.23 (n.s.)	T = 1.58; P = 0.13 (n.s.)	

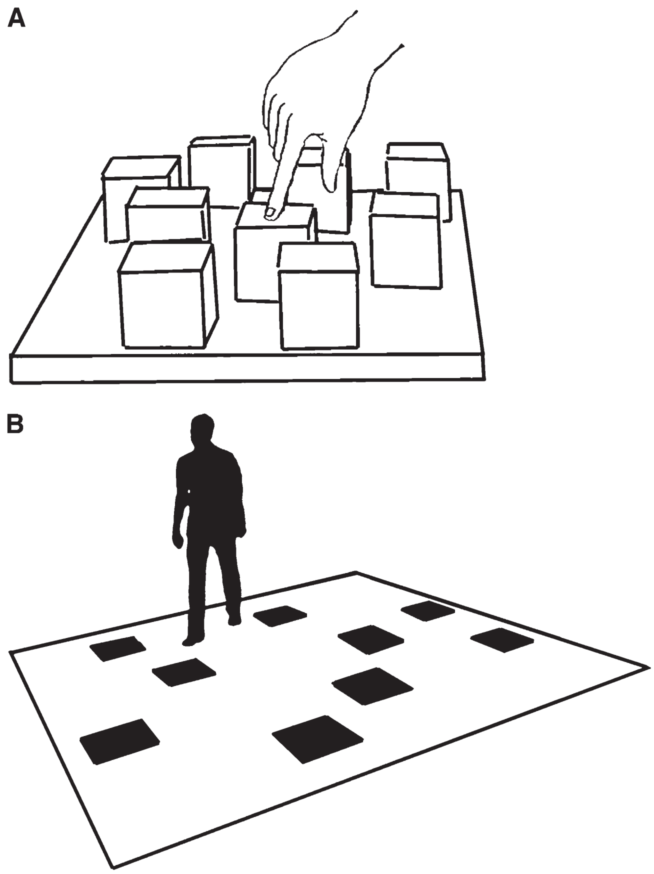

Fig. 1. A depicts the CBT layout; B depicts the WalCT layout (10:1 of CBT-M).

the traditional WalCT. The only difference was in computing the learning score, which was calculated by attributing one point for each block correctly tapped until the criterion was reached; then it was added to the score corresponding to correct performance of the remaining trials (up to the 18th; maximum score: 234). The order in which the CBT and WalCT was administered was counterbalanced across the subjects in each group.

Statistical Analysis

Data were analyzed using Statistica™ (StarSoft Italia) by means of three 2 × 2 mixed factorial ANOVAs, with Group (pilot and nonpilot) as between factor and Test (CBT and WalCT) as repeated measure, on the scores on Working Memory, Learning, and Delayed Recall. Post hoc analyses were performed using Bonferroni's correction for multiple comparisons. Also two one-way ANOVAs were performed considering Groups and their performance on the WalCT 13-step sequence on Learning and Delayed Recall. Multiple regressions analyses were performed to determine whether gender predicted performance in the CBT and the WalCT on Working Memory, Learning, and Delayed Recall, both considering the two groups (pilot and nonpilot) together and separately. For the Pilot group only we carried out regression analyses that also took into account flight hours.

RESULTS

Table II shows means and standard deviations (SD) for women and men in each group, with respect to Working Memory, Learning, and Delayed Recall in both the CBT and WalCT.

Working Memory

A 2 (Group: Pilot vs. Nonpilot) × 2 (Tests: CBT vs. WalCT) ANOVA was performed. The analysis did not show any significant effect [Group: $F(1,67) = 2.24$, $P = 0.14$; Tests: $F(1,67) = 1.00$, $P = 0.32$], but showed a significant Group x Tests interaction [$F(1,67) = 4.15$, $P = 0.14$; $P = 0.04$; ETA-Squared = 0.06; Observed Power = 0.52]. Specifically, the post hoc analysis showed that pilots performed significantly better in the CBT than nonpilots ($P < 0.01$, Bonferroni's correction for multiple comparisons).

A regression analysis carried out to determine whether Gender predicted performance in the CBT and the WalCT showed that Gender did not influence performance in either the CBT [adjusted $R^2 = -0.14$; $\beta = 0.28$; $F(1,67) = 0.51$, $P = 0.82$] or the WalCT [adjusted $R^2 = -0.01$; $\beta = 0.05$; $F(1,67) = 0.19$, $P = 0.66$]. We carried out regression analyses separately for the two groups (pilots and nonpilots) and found that gender predicted performance in the WalCT only in nonpilots [adjusted $R^2 = 0.11$; $\beta = 0.37$; $t\,(1, 27) = 2.05$, $P = 0.05$] but not in the CBT [adjusted $R^2 = -0.00$; $\beta = 0.18$; $t(1, 27)= 0.91$, $P = 0.37$].

For the pilot group we performed a regression analysis that also took into account flight hours. Also in this analysis no gender effects or flight hours effects emerged to explain performance on the two tests [CBT: adjusted $R^2 = -0.05$; Gender: $\beta = 0.243$, $t(1, 38) = -0.44$, $P = 0.66$; Flight Hours: $\beta = 0.00$, $t(1, 38) = 0.17$, $P = 0.86$] and [WalCT: adjusted $R^2 = -0.04$; Gender: $\beta = -0.09$, $t(1, 38) = -0.54$, $P = 0.60$; Flight Hours: $\beta = -0.06$, $t(1, 38) = -0.38$, $P = 0.71$].

Learning

A 2 (Group: pilot vs. nonpilot) × 2 (Tests: CBT vs. WalCT) ANOVA was carried out. The analysis did not show a significant effect of Group [$F(1,67) = 2.85$; $P = 0.09$], but showed a significant effect of Tests [$F(1,67) = 28.74$; $P < 0.001$; ETA-Squared = 0.29; Observed Power = 1], as well as a significant interaction of Group x Tests [$F(1,67) = 5.60$; $P = 0.02$; ETA-Squared = 0.07; Observed Power = 0.60]. Specifically, the post hoc analysis showed that pilots performed significantly better than nonpilots in the WalCT ($P < 0.01$, Bonferroni's correction for multiple comparisons), but did not differ from nonpilots in the CBT. Both groups performed better in the WalCT than the CBT ($P < 0.05$). A one-way ANOVA was performed considering Groups and their performance on the WalCT 13-step sequence. From this analysis it emerged that pilots performed significantly better than nonpilots [$F(1,67) = 4.44$; $P = 0.03$; ETA-Squared = 0.06; Observed Power = 0.55](**Fig. 2**).

A regression analysis was performed to investigate whether Gender predicted performance in learning the CBT and the WalCT. It resulted that Gender did not predict performance when all samples (i.e., both pilots and nonpilots) were

Table II. Results of Working Memory (VS-TM/TSTM), Learning (VS-L/TL/TL-13), and Delayed Recall (VS-DR/TDR and TDR-13) in Women and Men in the CBT and the WalCT. Means (SD).

GROUPS	VS-TM (*N* OF CUBES)	TSTM (*N* OF SQUARES)	VS-L (*N* OF CUBES)	TL (*N* OF SQUARES)	TL-13 (*N* OF SQUARES)	VS-DR (*N* OF CUBES)	TDR (*N* OF SQUARES)	TDR-13 (*N* OF SQUARES)
Male Pilots (N = 20)	5.8 (0.83)	5.55 (1.50)	119.15 (20.17)	136.85 (7.37)	204.2 (24.49)	7.35 (1.27)	8 (0)	12.85 (0.49)
Female Pilots (N = 20)	5.91 (0.70)	5.81 (1.44)	117.67 (17.66)	138.76 (3.75)	211.62 (12.80)	7.10 (1.81)	7.90 (0.30)	13 (0)
Male Nonpilots (N = 13)	5.38 (0.77)	5.54 (0.90)	116.04 (21.90)	123.28 (11.22)	191.93 (11.81)	6.62 (2.23)	7.42 (2.22)	11.48 (1.38)
Female Nonpilots (N = 15)	5.07 (0.88)	5.33 (0.90)	117.87 (19.43)	124.47 (18.96)	192.07 (22.75)	6.47 (3.18)	7.87 (0.52)	11.33 (3.04)

M-Pil = male pilots; F-Pil = female pilots; M-Nopil = male nonpilots; F-Nopil = female nonpilots; VS.TM = visual short-term memory measured by CBT; TSTM = Topographical Short-term Memory; VS.L = visual spatial learning measured by CBT; TL = topographical learning measured by the WalCT; TL-13 = topographical learning measured by the WalCT-13 steps; VS.DR = visuo-spatial delayed recall measured by the CBT; TDR = topographical delayed recall measured by the WalCT; TDR-13 = topographical delayed recall measured by the WalCT-13 step.

considered in both the CBT [adjusted R^2 = -0.01; β = 0.02; F(1,67) = 0.04, P = 0.85], the WalCT [adjusted R^2 = -0.01; β = 0.06; F(1,67) = 0.26, P = 0.61], and the WalCT 13-steps [adjusted R^2 = -0.01; β = 0.04; F(1,67) = 0.10, P = 0.75].

To investigate whether Gender predicted performance in the nonpilot group, we performed a regression analysis only for nonpilots and found that Gender did not predict performance on any of the three tasks: [CBT: adjusted R^2 = -0.03; Gender: β = -0.12; t(1, 27) = -0.59, P = 0.56]; [WalCT: adjusted R^2 = 0.01; Gender: β = 0.22; t(1, 27) = 1.14, P = 0.26]; [WalCT-13: adjusted R^2 = 0.12, Gender: β = 0.33; t(1, 27)= 1.81, P = 0.08].

We also investigated whether Gender and Flight hours predicted performance in the pilot group by means of a regression analysis. We found that neither Gender nor Flight hours predicted performance in the CBT [adjusted R^2 = -0.05; Gender: β = 0.05; t(1, 38) = 0.29, P = 0.77; Flight hours: β = -0.06; t(1, 38)= -0.38, P = 0.71]; the WalCT [adjusted R^2 = -0.02; Gender: β = -0.17; t(1, 38) = -1.03, P = 0.31; Flight hours: β = -0.02; t(1, 38)= -0.15, P = 0.88]; and the WalCT 13-steps [adjusted R^2 = -0.01; Gender: β = -0.19; t(1, 38) = -1.20, P = 0.24; Flight hours: β = -0.01; t(1, 38) = -0.06, P = 0.95].

Delayed Recall

A 2 (Group: Pilot vs. Nonpilot) × 2 (Tests: CBT vs. WalCT) ANOVA was performed. The analysis did not show any significant effect for Group [F(1,67) = 0.76; P = 0.38] or significant interaction for Group x Tests [F(1,67) = 0.67; P = 0.41]. However, a significant difference between Tests [F(1,67) = 7.31; P = 0.01; ETA-Squared = 0.11; Observed power = 0.76] emerged, which showed that both groups had better delayed recall of sequences on the WalCT than the CBT. A one-way ANOVA was performed considering Groups and their performance on the WalCT 13-steps sequence. This analysis showed no significant differences between pilots and nonpilots [F(1,67) = 2.1; P = 0.06], once again suggesting that the learning phase is crucial to show differences between experts and nonexperts.

A regression analysis performed in both groups to investigate whether Gender predicted performance in delayed recall in the two tests showed that Gender did not predict performance in the CBT [adjusted R^2 = -0.01; β = - 0.09; F(1,67) = 0.59, P = 0.45], the WalCT [adjusted R^2 = 0.0; β = -0.14; F(1,67) = 1.22, P = 0.27], or the WalCT 13-steps [adjusted R^2 = -0.0; β = 0.11; F(1,67) = 0.83, P = 0.37].

To determine whether Gender predicted performance in the nonpilot group, we performed a regression analysis only for nonpilots and found that Gender did not predict performance: [CBT: adjusted R^2 = - 0.03; Gender: β = -0.07; t(1, 27) = -0.34, P = 0.74]; [WalCT: adjusted R^2 = - 0.02; Gender: β = -0.14; t(1, 27) = -0.73, P = 0.47]; and [WalCT 13-steps: adjusted R^2 = 0.02; Gender: β = 0.24; t(1, 27) = 1.26, P = 0.22]. This result is in agreement with previous reports[29,31,34] in which no gender effects emerged in the delayed recall of previously acquired information.

We also investigated whether Gender or Flight hours predicted performance in the pilot group by means of a regression analysis that excluded the nonpilot group. We found that in

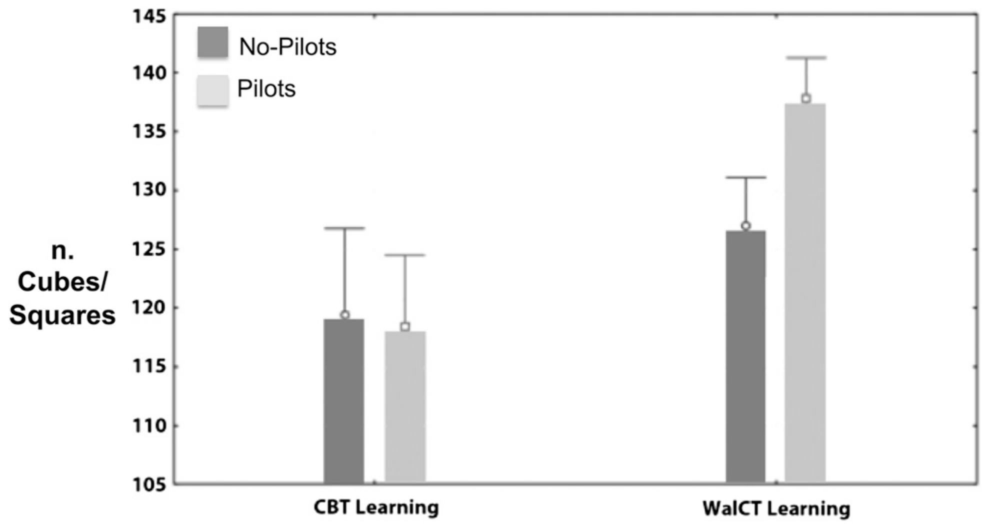

Fig. 2. Significant interactions evidenced in working memory and learning. Light-gray identifies Pilots, while dark-gray identifies Nonpilots.

pilots neither Gender nor Flight hours predicted performance in the CBT [adjusted $R^2 = 0.05$; Gender: $\beta = -0.10$; $t(1, 38) = -0.65$, $P = 0.52$; Flight hours: $\beta = -0.29$; $t(1, 38) = -1.87$, $P = 0.07$], the WalCT [adjusted $R^2 = -0.04$; Gender: $\beta = 0.22$; $t(1, 38) = 1.34$, $P = 0.19$; Flight hours: $\beta = 0.01$; $t(1, 38) = 0.05$, $P = 0.96$], and the WalCT 13-steps [adjusted $R^2 = 0.0$; Gender: $\beta = -0.22$; $t(1, 38) = -1.41$, $P = 0.17$; Flight hours: $\beta = 0.06$; $t(1, 38) = 0.36$, $P = 0.72$].

DISCUSSION

The aim of the present study was twofold: to investigate the presence of differences in reaching vs. navigational memory in pilots vs. nonpilots and a possible gender effect in the pilot population. The novelty of the study was in assessing the pilots' capability in reaching and navigational memory as well as the presence of any gender effect in this population. To our knowledge no other studies have investigated these skills in pilots. Our findings show the absence of gender effects in pilots with respect to the general population as regards visuo-spatial abilities, not due to the experience (flying hours),[40] but to the selection process, as fully explained in the following discussion. The selection process promotes the choice of people with high visuo-spatial abilities that per se excludes more women than men. Then the training of navigational ability in these highly selected people has the same efficacy and operational impact regardless of gender.

The major finding of our study was that we did not find any gender difference in a population of pilots; while in agreement with the current literature,[8,22,29] we found gender effects in the control group in solving navigational tasks, specifically in those involving working memory. We also found that pilots performed better than nonpilots.

We investigated two different types of visuo-spatial memory, namely, navigational versus reaching memory. For this purpose we used the WalCT to test memory in the navigational domain and the CBT to assess memory in reaching space. We evaluated the two types of memory by taking into account temporal duration (working memory and long-term memory) and focused on working memory and the learning phase, which is considered critical in the gender differences literature. In general, working memory allows maintaining on-line information and differs from long-term memory, which allows off-line information retrieval. Working memory ability is the basis of good performance in visuo-spatial tasks. According to Coluccia and Iosue,[8] the difference in performance could be "masked" by cognitive task demands. Specifically, spatial tasks with high cognitive demands produce gender differences, while those with low cognitive demands do not.[33] We found that pilots process on-line information in reaching and navigational space with the same high level of competence, and that nonpilots have difficulty in reaching space, as demonstrated by their performance in the CBT with respect to the WalCT. Our data are consistent with the observation that pilots have enough ability in managing real-time on-line information coming from the instrument panel and navigational information coming from the external environment. The combination of working memory information (i.e., reaching and navigational) is given during the approach and landing phases in which the pilot has to check and merge both kinds of information. We did not find gender differences in pilots in navigational tasks, which is consistent with previous data by Verde et al.[40] in which no differences were found between male and female military pilots in mental rotation tasks. In the nonpilot population, gender differences emerged in navigational working memory, which supports the previous findings that men are more competent than women in spatial navigation.[20]

With regard to learning, no differences were found between pilots and nonpilots in reaching space, which was evaluated with the CBT, while pilots performed much better than nonpilots in the WalCT.

As reported in several studies,[18,24] navigating in the environment requires continuously changing perspective, which in turn makes high cognitive demands on representing and transforming previously acquired mental representations. Navigational competence in daily job activities of a pilot is very important and pilots are selected also for their visuo-spatial abilities, on which navigational memory is based.

As shown in **Table III**, the current selection process for military pilots in Italy involves a multistage process with several pass/fail steps. These steps include: measures of ability (e.g., standardized test scores), medical qualification, physical fitness, indicators of officership, personality assessment, fitness for intellective efficiency, ten days of apprenticeship in military academy with subsequent examination of a written composition of Italian, oral examination of English, oral examination of math (geometry, algebra, trigonometry).

In the stage of the intellectual efficiency, several batteries of tests are administered to candidates for assessing cognitive ability. A particular battery of tests with which women have difficulty is the PILAPT, now replaced by the similar VIENNA test. PILAPT's battery is composed of different categories of computerized tests arranged on several levels of difficulty. These tests relate to different cognitive domains estimated under conditions of stress, such as attention, memory, logical reasoning ability, perceptual skills, and hand to eye coordination for the estimation of properties of 3-dimensional structural characteristics.

Of course both selection and training play important roles in producing effective pilots who will allow the organization to meet its goals. Effective selection procedures will produce cost-avoidance savings through reduced attrition and reduced training requirements. Nevertheless, there are so many factors in the overall pilot performance that selection of people with high visuo-spatial abilities does not predict good performance in flight, but when a candidate does not possess these cognitive abilities he is less likely to become a good pilot since they are crucial for aircraft navigation.

As evidenced by the selection database and criteria for entering the Italian Air Force Academy, women who pass the trials are already strongly selected for their high spatial abilities and are subsequently selected for their mathematical skills (Verde P. Aircrew selection. Dec. 2013; internal report, unpublished). It is well known that these abilities are strong in men.[24,31] Indeed, a male advantage has been found in several visuo-spatial tasks, such as mental rotation, and in spatio-temporal tasks.[40] With regard to mathematical ability, men are considered to be more accurate and faster in solving problems than women.[10,12,14] The male advantage in solving mathematical problems seems to be mediated by a general advantage in spatial cognition, because men are better than women in generating spatial representations or diagrams of the relational information conveyed in problems. These abilities could reduce the frequency of problem-solving errors.[10] According to Kimura and Hampson,[17] women's work performance changes in accordance with estrogen fluctuations. In particular, when hormones increase, spatial skills are decreased but manual and talking skills are increased.

Indeed, in the past 3 yr the following data emerged for candidates who attempted to enter the Academy (Verde P. Aircrew selection. Dec. 2013; internal report, unpublished). In the first year, out of all women admitted to the selection, only 41.18% passed the visuo-spatial battery of tests, and only 33.33% of the remaining subjects passed the mathematical tests. On the contrary, out of all men admitted to the selection, 69.34% passed the visuo-spatial battery of tests and 41.18% of the remaining subjects passed the mathematical tests. In the second year, out of all women admitted to the selection, only

Table III. Subsequent Stages of Pilot Selection for the Italian Air Force Academy.

					TEN DAYS APPRENTICESHIP IN THE ITALIAN AIR FORCE ACADEMY			
ENTRANCE AT REGULAR COURSES FOR PILOTS (ITALIAN AIR FORCE ACADEMY)	GENDER	PASSED AT STANDARDIZED TEST SCORES	PASSED AT MEDICAL QUALIFICATION AND PHYSICAL FITNESS TRIAL	PASSED AT INTELLECTUAL EFFICACY / PILAPT OR VIENNA TEST	FIT FOR OFFICERSHIP AND PERSONALITY ASSESMENT	PASSED AT ITALIAN COMPOSITION	PASSED AT ENGLISH EXAMINATION	PASSED AT MATHS EXAMINATION
2011	M	95.83%	89.63%	69.34%	67.53%	82.05%	89.06%	73.68%
	F	95.00%	89.47%	41.18%	85.71%	85.71%	85.71%	33.33%
2012	M	93.39%	92.92%	68.85%	76.98%	78.35%	98.68%	90.67%
	F	93.33%	85.71%	50.00%	83.33%	83.33%	83.33%	66.67%
2013	M	96.34%	91.94%	86.60%	81.55%	67.15%	94.56%	85.06%
	F	100.00%	75.00%	55.56%	83.33%	83.33%	83.33%	20.00%

50.00% passed the visuo-spatial battery of tests and 66.67% of the remaining subjects passed the mathematical tests. On the contrary, out of the total men admitted to the selection 68.85% passed the visuo-spatial battery of tests and 90.67% of the remaining sample passed the mathematical tests; in the last year, out of all women admitted to the selection only 55.56% passed the visuo-spatial battery of tests and only 20.00% of the remaining sample passed the mathematical tests. On the contrary, out of all men admitted to the selection 86.60% passed the visuo-spatial battery of tests and 85.06% of the remaining sample passed the mathematical tests. With reference to these data, the absence of gender effects in our pilot sample is justified by the strict selection carried out at the beginning of their career.

As underlined by Coluccia and Iosue,[8] in this type of task, women are at a disadvantage with respect to men. It is noteworthy, however, that this is specifically true for navigational working memory. The latter requires an active cognitive load because moving through an environment entails continually changing perspective, which has to be updated every time a new orientation is presented. Nori et al.[23] also predicted that the moving reference frame constituted an additional load for the spatial component of visuo-spatial working memory. Interestingly, our data further support the absence of gender effects in both pilots and nonpilots in delayed recall of navigational and spatial information. These results highlight that once environmental representation is acquired and stored it can be easily recalled by both genders.

To our knowledge, only three studies mention spatial ability and gender differences with regard to military pilots. Koonce and Berry[19] investigated gender differences in predicting flight training performance in simulators and found that female cadets were faster on perceptual tasks. By contrast, male cadets were quicker on visual memory, spatial orientation, spatial scanning tasks, and psychomotor tasks. Results showed no overall difference between men and women in basic flying abilities. Carretta[7] studied the gender differences in the selection tests of U.S. Air Force pilots and found no reliable evidence of differences in skill between the two genders. Verde et al.[40] investigated gender effects in mental rotation and found no difference between male and female pilots. These few studies suggest that once Air Force men and women are selected as pilots they do not differ from each other, but strongly differ from the general population in visuo-spatial abilities, mathematical skills, and spatial navigation.

The major limit of our study is that we recruited a small group of female pilots. All the female pilots enlisted in the Italian Air Force at the moment of the study were considered and two of them were excluded because they were left-handed. Thus, the number of subjects in each subgroup was set accordingly

In conclusion, although in the general population men are better than women in navigational abilities, according to our findings in pilots there is no gender based difference, maybe due to the fact they are selected on the basis of their visuo-spatial abilities.

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