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Engineers' abilities influence spatial perspective changing

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Abstract- *In this paper we studied the effect of engineering expertise in providing directional judgments. We asked two groups of people, engineers and non-engineers, to observe and memorize five maps, each including a four-point path, for 30 sec. The path was then removed and the participants had to provide two directional judgments: aligned (the imagined perspective on the task was the same as the one just learned), and counter-aligned (the imagined perspective on the task was rotated by 180°). Our results showed that engineers are equally able to perform aligned and counter-aligned directional judgments. The alignment effect due to the distance from the learning perspective was, in fact, shown only by non-engineers. Results are discussed considering engineering both learning expertise and specific predisposition.*
Keywords *– Engineering, Expertise-job related; Individual Difference; Perspective Taking, Spatial Memory*

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1. Introduction

According to the European Space for Higher Education in the engineering degrees spatial ability appears as one of the skills that should be acquired by students (Ministerial Conferences, every two years since 1999). Spatial ability helps humans in different aspects, such an example: in reaching a goal, orienting in a new environment, estimating distances, finding shortcuts and so on. Individual differences consist in active strategies to solve spatial reasoning problems [1-4], with some people displaying a better innate spatial ability than others. However, this skill may be reached in later stage of the life through practice and patience [5-6]. Navigation is part of the general spatial ability and encompasses different cognitive processes. Indeed, successful navigation requires being able to recognize and remember landmarks and their positions, linking the landmarks each other and to the environment [7]. The individual differences present in navigation through different tasks have been thoroughly investigated [8-9]. For example, the Perspective Taking/Spatial Orientation Task (PTSOT) [10] has been created [11-12] with the aim to test the capability to take different imagined perspectives, a skill used to predict the performance in the large-scale environment. The PTSOT requires people to point the location of an "object" from an imagined perspective determined by further two objects. The magnitude of the difference between the individual's egocentric perspective and the imagined one makes the task more difficult. There are two different frames of reference in environmental mental representation, namely egocentric and allocentric representations of the environment. Egocentric representation consists in the relation of an environmental object with respect to the self, whereas allocentric representation represents the location of the environmental object with respect to external coordinates [13].

When individuals perform directional judgments, these judgements are more faster and accurate when there is a match between the learned perspective and the imagined one (i.e. alignment effect orientation), compared to when the perspective is counter-aligned, that means rotated by 180° (i.e. counter-alignment effect; [14]) or by some degree (i.e. misalignment effect; [15]). This is known in the literature as alignment effect [11; 16], which occurs when it is required to mentally recall an environment previously learnt in a different perspective [17-18]. Spatial orientation abilities have a crucial role in the daily life, this variable has studied in many ways to attenuate or eliminate this effect. For example, when people learn the environment directly, no alignment effect is observed [17; 19-20]. This effect is also influenced by individual tracts, such as the spatial cognitive style [21], which consists in the kind of information selected and extracted from the environment to navigate and orient themselves [22-27]. Other studies took into account gender and age. Specifically, Zancada-Menendez et al. [2] compared groups of participants, with different age range and gender, during a direction judgment task and found that males outperformed females regardless of age. Furthermore, younger participants displayed better performances compared to older participants, maybe due to the weakening of working memory and visuo-spatial abilities, which decrease with age.

Only the non-aligned condition is affected in people skilled in mental rotation task [28]. A very recent study by Piccardi et al. [29] demonstrated that the visual mental imagery components (generation, inspection and transformation) negatively correlate with inaccuracy during directional judgments. In particular, generation plays a pivotal role in aligned directional judgments, whereas the other components predict the ability to perform counter-aligned directional judgments. All these components are fundamental in remembering a map, only people clever in inspecting and mental rotating an objects are more accurate in changing perspective. It is interesting to note that the possibility to develop some spatial abilities, specifically mental rotation, seems to be affected by the educational background [30]. A good space conceptualisation is needed for engineering, and for science and mathematics disciplines [31]. In many engineering problems, spatial abilities contribute to understand the forces acting on an object, to draw free-body diagrams, to retrieve spatial cues from a system, and how the objects move in space over time. Findings show that spatial skills have an important role in developing expertise in science, technology, engineering, and mathematics (STEM) education [32-37]. In line with the theory of cognitive coordinate systems, engineering problems that involve the combination of translational and rotational motions and the translation of reference frames (such as inclined plane problems)require greater spatial cognitive resources [38]. Students less skilled in spatial orientation tasks experience more difficulty to retrieve and elaborate spatial cues from the exercises treated during the courses [37]. It is known that spatial-related experience, important in engineering and science background, has a significant impact on the building of spatial skills. Indeed, findings demonstrate that spatial capability can be enhanced during the training [32-33; 36; 39]. Spatial ability training in an engineering school, usually lasts a semester and strengthens spatial abilities that would be critical, such as isometric sketching, cross section identification, mental rotation and net development [33; 40]. This type of learning experience helps students to be confident with new information by spatial problem solving, thus contributing to the development of spatial planning, flexibility and working memory. In a research, 153 students attending a preliminary engineering course at the University of California improved their spatial skills and their marks just with a one-day spatial training, even reducing gender differences [32].

The goal of this study was to investigate how the role of spatial-related experience in engineers could explain individual differences in a specific spatial bias, such as the alignment effect. Specifically, we expected that the development of spatial flexibility and spatial working memory, typically associated to engineering studies, could eliminate or attenuate the alignment effect. We hypothesized that engineers would perform better, taking the same time to perform both aligned and counter-aligned judgments, compared to participants from a different study environment (i.e., psychologists).

2. Methods

2.1 Participants

Forty men (20 military engineers and 20 non-engineers) took part in the study. The military engineers group ranged from 23 to 36 years of age (M = 32.25 y, S.D. = 3.31 y) while the non-engineers group ranged from 25 to 40 years of age (M = 30.95 y, S.D. = 3.94y; age did not differ among groups [$F(1,38)= 1.27$; $p = .26$]) and was constituted by psychologists. All subjects were graduated. In the Italian Air Force, military engineers could come both from the Military Academy or from civilian schools of Engineering and they have to win a national competition to join the Air Force. In our sample all engineers come from the Military Academy. The educational course for the Military Academy includes a 5-year of regular School of Engineering combined with several practical activities ranging from sports (i.e., rowing boat competition; sailing; orienteering) and combat and survival courses. Specifically, they were enrolled from the Flight Experimental Centre of Pratica di Mare AFB (Pomezia (RM), Italy). The psychologist enrolled in this study have attended a regular civilian school of Psychology at the University of Bologna (Bologna, Italy). It is worthy to mention that in the Military Academy are not available courses for psychologists and all military psychologists come from civilian schools of Psychology. The two groups are comparable for age and years of education and for being talented students selected according to their final graduation score. Only men were recruited to obtain performance from a homogeneous sample and taking into account for their proficiency in mental rotation tasks with respect to women. Indeed, in this task, it is well-known that males outperform females, both in response accuracy and in time spent to perform mental rotations (for a review see [41]). So in order to eliminate gender differences we decided to enrol only men in such a way the presence of any differences could be interpreted in terms of type of occupation and education.

In the military engineers group there were 2 left-handed participants, while in the non-engineers group there was only 1 left-handed participant. All participants gave their written informed consent in agreement with the Declaration of Helsinki and they did not complain any symptom of psychiatric or neurological illness. The study protocol was approved by the local ethical committee.

2.2 Materials

Seven paths of the series used by Levine et al. [11] were selected for this work, in order to test the alignment effect. These seven paths were composed of three segments of different lengths, two nodes, a starting point and a final point. Each path had two turns, formed by angles that were either 70° and 110° or 90° and 90°. Two of the seven paths were used for practice. Each path was printed on A4-paper (21 cm x 29.7 cm), composed by segments of variable length, ranging from 3.5 cm to 17 cm [14]. A number from 1 to 4 was assigned to each of the points, considered as part of the paths in a sequential fashion: 1 at the starting point, 2 and 3 at the nodes and 4 at the last point of the sequence ([17]; see Figure 1).

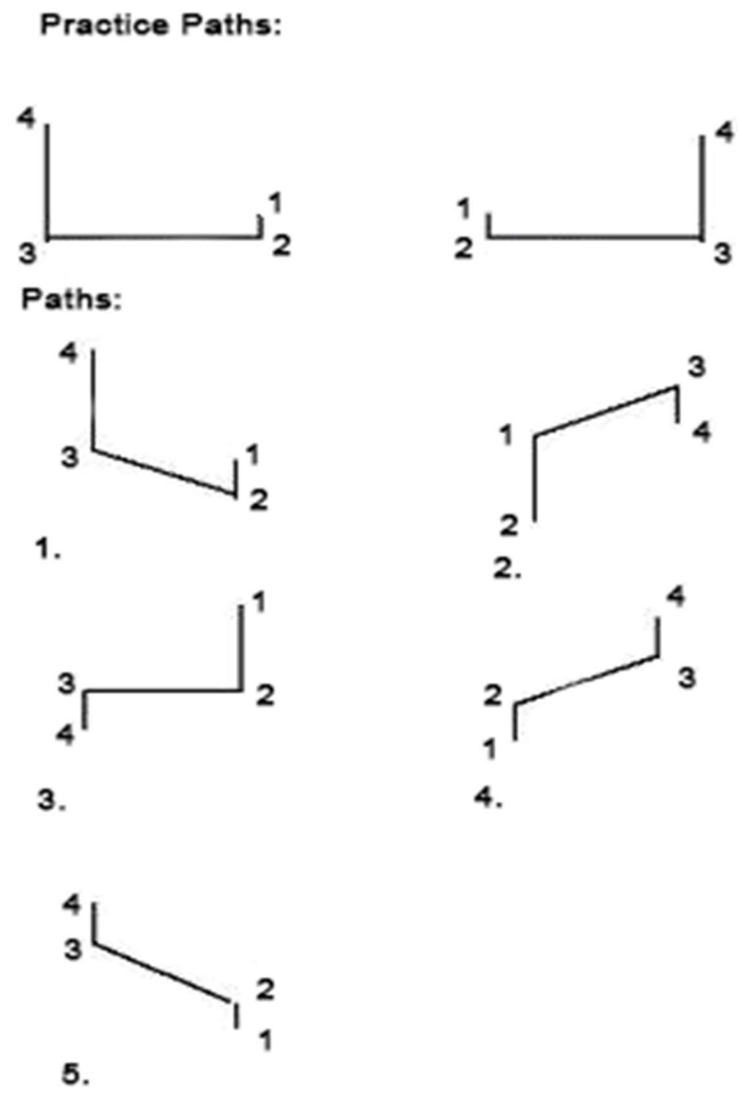

Figure 1. Seven paths used for the experiment : three segments of different lengths, two nodes, a starting point and a final point. The first two paths (upper) were used for practice. A number from 1 to 4 was assigned to each of the points, considered as part of the paths in a sequential fashion: 1 at the starting point, 2 and 3 at the nodes and 4 at the last point of the sequence

In order to give their directional judgments, participants used a cardboard dial, with a diameter of 30 cm and provided with a pointer, positioned in the middle of the dial, which could be rotated by 360°. A similar instrument had been used before in previous studies [15]. The circular dial was marked clockwise every 5°, enabling to register the participants' responses. The angulations of 0°, 90°, 180° and 270° were marked by notches on the dial, for helping participants to identify the right direction. The 0° position was marked differently, in order for the participants to maintain 0° in forward position.

2.3 Procedure

Each participant was informed that s/he would learn a series of four-point paths and would then have to respond to two directional judgment tasks. Before starting the task, the instructions about how to use the cardboard dial were explained. Participants then observed each of the five paths for 30 seconds. During this time, the participants had to learn the position of the numbers on the path. The path was then removed and the researcher put the cardboard dial in front of the participants, in order to let them perform the directional judgment tasks. The researcher instructed their participants to imagine themselves starting at a specific point of the path, to look at another point and indicate the target on the path by the means of the circular dial. On each path, participants had to express two directional judgment tasks: in one task, participants had to give aligned judgments (the perspective on the task was the same as the learned one); in another task, the judgments were counter-aligned (the perspective on the task was rotated by 180°), in order to verify the presence of the alignment effect. In total, there were five aligned direction tasks and five counter-aligned direction tasks. Half of the participants made the aligned judgments before the counter-aligned and vice versa, randomly. The correct response for aligned and counter-aligned judgments, ranging from 45° to 315°, could be either in front of or behind the participants.

The five paths were randomized, but the same order was presented to every participant ([14-15]). When participants solved one path, the same procedure was used for the subsequent path.

The researcher recorded the response time in seconds, starting just after the target position was revealed and stopping when participants ended to indicate the judgement on the dial. The researcher also recorded the angular direction given by the participants (in degrees), reading it from the dial. It was therefore possible to calculate the absolute angular error, given by the difference between the correct position and the position given by the participant.

3. Results

A three-way mixed design ANOVA was performed, with two levels of group as between variable (military engineers vs. non-engineers), two levels of directional judgments as within variable (aligned/counter-aligned) and five levels of paths as repeated factor and within variable. These independent variables were taken into account on the absolute angular error and the response time.

3.1 Absolute angular error

The main effect of the "group" level was statistically significant [$F(1,38) = 42.24$, $p < 0.001$, partial $\eta 2 = 0.53$]. The military engineers ($M = 27.68°$, $S.D. = 5.97°$) performances were more accurate compared to non-engineers ($M = 82.59°$, $S.D. = 5.97°$). The main effect of the "directional judgment tasks" was also statistically significant [$F(1,38) = 54.26$, $p < 0.001$, partial $\eta 2 = 0.59$], with the aligned judgments ($M = 24.99°$, $S.D. = 2.92°$) resulting easier than the counter-aligned judgments ($M = 85.28°$, $S.D. = 7.79°$). The main effect of the paths level was not statistically significant [$F(4,35) = 2.01$, $p = 0.12$, partial $\eta 2 = 0.19$]. With respect to the interaction between these variables, a statistical significance emerged in the interaction "groups x directional judgment tasks" [$F(1,38) = 24.78$, $p < 0.001$, partial $\eta 2 = 0.40$]. Pairwise comparison with Bonferroni correction showed that counter-aligned judgment tasks were more difficult ($p <0.001$) than aligned judgment tasks for the non-engineers group. Conversely, in the engineers group there was no difference between the aligned and counter-aligned judgments ($p = 0.09$). Means and standard deviations are reported in Figure 2.

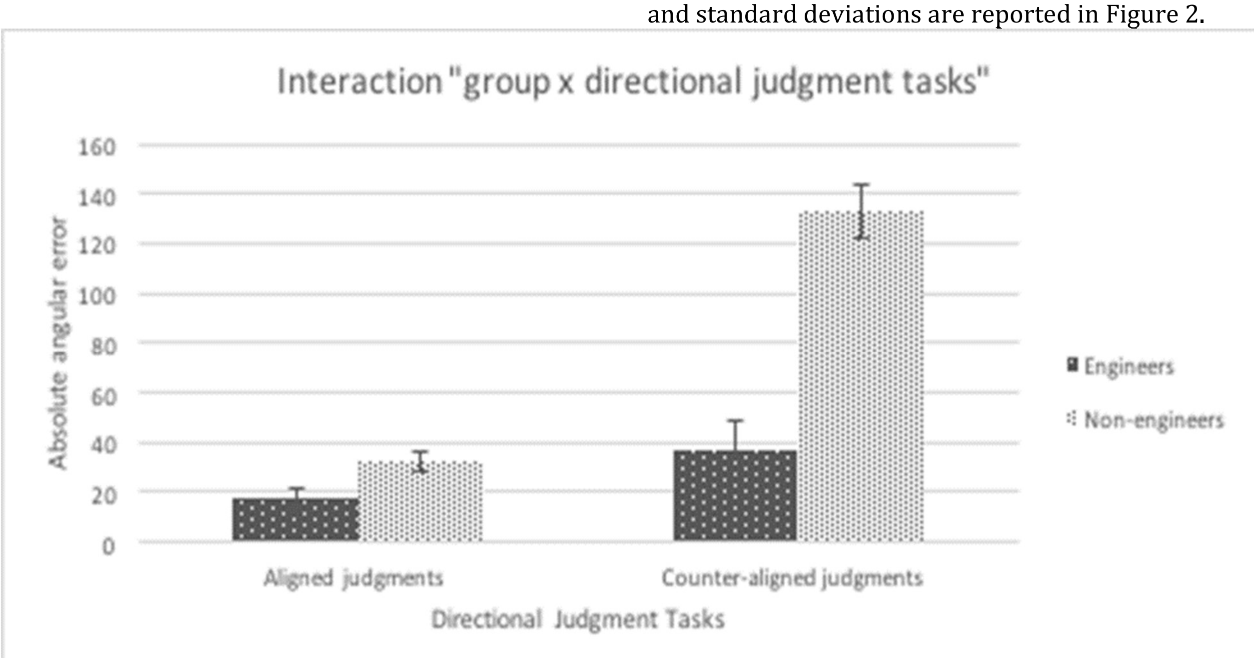

Figure 2. Mean and standard deviation of the absolute angular error considering the two group (engineers vs. non-engineers) in providing aligned and counter-aligned directional judgment tasks

3.2 Response time

The main effect of the "group" level was statistically significant [$F_{(1,38)} = 9.28$, $p < 0.05$, partial $\eta^2 = 0.20$], with the military engineers (M = 12.15 sec., S.D. = 0.96 sec.) taking longer than non-engineers (M = 8.00 sec., S.D. = 0.97 sec.) in performing directional judgments. The main effect of the "directional judgment tasks" was also statistically significant [$F_{(1,38)} = 46.25$, $p < 0.001$, partial $\eta^2 = 0.55$]: participants performed aligned judgments (M = 7.60 sec., S.D. = 0.53 sec.) faster than counter-aligned ones (M = 12.55 sec., S.D. = 0.96 sec.). A statistically significant main effect of the paths level [$F_{(4,35)} = 5.10$, $p < 0.05$, partial $\eta^2 = 0.37$] was also observed. Pairwise comparison with Bonferroni correction showed that making judgments in path 3 took less time ($p < 0.01$) than in path 4. Means and standard deviations are reported in Figure 3. No other significant differences were reported.

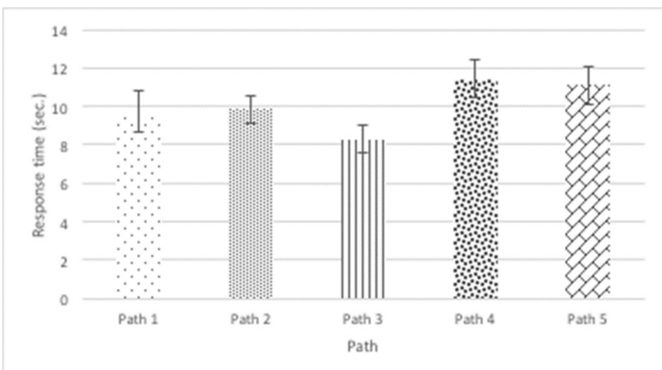

Figure 3. Mean and standard deviation of the response time spent by participants in the five paths.

Moreover, in order to better understand the results about response time in military engineers group, we performed a regression analysis considering the mean of response time in the five paths as independent variable and the mean of absolute angular errors in the five paths as dependent variable in counter-aligned judgments. The results did not show any significant prediction ($F_{(1, 19)} = 3.74$, $p = .06$, $r^2 = .12$, Beta = -.41).

4. Discussion

The aim of this study was to explore the role of spatial-related experience in engineers and whether it could explain individual differences in alignment effect. Specifically, we hypothesized that engineers would perform better, taking the same time to perform both aligned and counter-aligned judgments, compared to psychologists.

Like for similar other cognitive dimensions ([39; 42-44]), individual's professional experience, as well as professional training, may mitigate the effects on performance. In this view, our results confirm our hypothesis that engineers were able to perform equally well in both directional judgments, even if they took more time to accomplish it. A possible explanation could be related to a perceived self-efficacy: it is likely that engineers are aware about their proficiency in mental rotation tasks and as a consequence they spent more time to solve the task in accurate way because it is considered as challenge regarding their know-out, while psychologists may perceive themselves less proficient and experience a less challenge experience in performing the task. According to Bandura [45] self-efficacy is a sort of a motivational factor and it is the individual's belief in the own capability to accomplish a task. Self-efficacy has moreover effects on several different domains, such as academic motivation, self-regulation during learning [46] and in promoting sporting achievements [47]. An increased self-efficacy with respect spatial ability may come from the evidence that spatial cognition develops by engineers over time during different periods of life as a consequence of the exposure to different learning environments [48] and probably by a specific interest about these specific aspects. Accordingly, engineers showed higher ability to imagine a particular path from different points of view, and were able to retrieve the correct direction of an applied force vector, having developed high spatial skills. On the other hand, low spatial learners had less cognitive resources for imagining and manipulating the environmental images [49, 37]. Several life experiences, such as videogame usage and computer , are linked to spatial skills [50-59], and the impact of computer training has been associated with an increase of the spatial ability [50, 58, 60-61], specifically the one involved with mental rotation skills. The learning of complex spatial abilities requires training in specific areas that encourage visuo-spatial activities, as experienced and practiced during university and post-university training. In particular, it is possible that university and post-university specific training might improve mental rotation ability. It is therefore feasible that, after their specific training, engineers would improve their visual information retention compared to people who did not have that specific training. According to this point of view, some studies [62-63] have shown that the study of mathematics develops brain regions responsible for visualization and spatial ability in case of high working memory demands. Chen and Whitehead [64] have also highlighted that physics requires a specific training in working memory. Indeed, the difference in performance of engineers, compared to non-engineers, could also be interpreted considering the task-cognitive demand [65]. A perspective changing task, such as counter-aligned judgments, requires high cognitive demand in representing and transforming the mental representation previously acquired from a different point of view. The cognitive load is greater when increases the number of interacting elements to maintain simultaneously in the working memory [66]. Nevertheless, working memory is a limited resource that can overload. To go beyond this limit, it needs to organize learned information into schemes that allow to be more efficient during the learning process, thus optimizing the material to be learned. Reduction of the cognitive load occurs both when the individual is familiar with the situation (the expertise effect), as well as when the individual has a high working memory capacity, which allows him/her to simultaneously maintain information online.

Consequently, differences could be detected in spatial orientation tasks that involve a consistent visuo-spatial working memory load. These span differences are particularly marked in active tasks, where participants are required to elaborate, integrate and transform the visual imagined material. Accordingly, in the general population, a poor performance in mental rotations produces more errors in pointing tasks during the counter-aligned condition, compared to aligned, and with different degrees of orientation conditions [28]. However, Piccardi et al. [29] also found that other mental imagery components, such as visual mental inspection, give a contribute when individuals have to perform directional judgments with different orientation. The capability to transform a mental image has a role when individuals have to provide counter-aligned directional judgments, stressing that the mental transformation gives a contribute when the cognitive load increases. The research reported in this paper shows that military engineers have higher spatial ability than psychologists. Specifically, they were better in providing directional judgements that is a spatial skill related to the spatial orientation capability. Engineers are less affected by the alignment effect, showing a lower sensitivity to spatial bias, analogously to what happens with the topographical memory during environmental interference in pilots [43]. It is possible that their skill resulted from the special education they received attending the Military Academy instead of the civilian school of Engineering but it could also be possible that they have the genetic makeup to make these skills easier or that they have developed them from early and middle childhood activities. Nevertheless, some works have shown the link between spatial and mathematical performance (e.g., [67-68]). Indeed, both representation and decoding of complex mathematical ideas is established on the strength of spatial ability [69-71]).

Despite our results are interesting and suggest some practical educational directions (i.e., adding practical courses also in the civilian schools of Engineering) this study has some weaknesses. Firstly, sample size was limited from our choice to enrol only military engineers coming from Military Academy. Furthermore, this choice impeded us to compare military engineers coming from Military Academy with those coming from civilian field. As a consequence, we could not conclude that engineers generally speaking are better than psychologists, even if we expected that also civilian engineers are better than psychologists, taking into consideration the link between mathematical skills and spatial abilities owned by engineers. Moreover, also for being admitted to the civilian school of engineering, students have to pass the entrance exam that includes mathematical reasoning, visuo-spatial abilities, geometrical competencies and logical reasoning. We are planning to pass this limit in a future study when participants will both come from Military Academy and civilian schools. On the other hand, it is difficult to attribute the origin of the engineering expertise that could be the result of the training or of the attitude. Actually, people who choose to study engineering have already strong skills in the area of interest and for such a reason the education could only be a part of the observed skill set [72]. Finally, participants to our study were only men, surely this allow us to have a homogeneous sample without the well-known gender-related effects on spatial abilities [41, 73], anyway it could be of interest to observe whether gender differences are still present within engineers category, it is possible that both men and women engineers could be more proficient of men and women coming from other occupation as happens in military pilots (see [39]).

Another limitation is that our spatial tasks required transformation of two-dimensional objects. Other investigations should comprehend 3-D mental rotation tasks with more trials and other aspects of visuo-spatial reasoning as these could be influenced by diverse aspects of mathematics.

We believe that the present study, despite the above limitations, could be useful to provide insights in planning new individualized approaches to fostering spatial ability, supporting intellectual development in other areas in engineering courses.

5. Conclusion

The present study confirms the importance of the spatial abilities in education in order to solve correctly daily spatial problem. Educators should be aware of the role of spatial ability, that is mentally manipulate, rotate, twist or invert stimuli, and provide proper training strategies to help students improve their skills when approaching spatial problems.

Even Hegarty et al. [74] stressed the correlation between spatial abilities with success in science, suggesting "…the need for studies of the role of spatial thinking in science to be mindful of both varieties of spatial intelligence and varieties in the spatial demands of different sciences" (pp. 93).

From this point of view, these results call for further studies aimed at identifying particular environmental mediators of the spatial orientation-mathematics relationship.

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References

[1] Shelton, A.L., Gabrieli, J.D., 2004. Neural correlates of individual differences in spatial learning strategies. Neuropsychology, 18, 442–449.

[2] Zancada-Menendez, C., Sampedro-Piquero, P., Lopez, L., McNamara, T.P., (2016). Age and gender differences in spatial perspective taking. Aging Clinical and Experimental Research, 28(2), 289-296.

[3] Bocchi, A., Carrieri, M., Lancia, S., Quaresima, V., Piccardi, L., 2017. The Key of the Maze: The role of mental imagery and cognitive flexibility in navigational planning. Neuroscience Letters, 651, 146-150.

[4] Carrieri, M., Lancia, S., Bocchi, A., Ferrari, M., Piccardi, L., Quaresima, V., 2018. Does ventrolateral prefrontal cortex help in searching for the lost key? Evidence from an fNIRS study. Brain Imaging Behavior, 12(3), 785-797.

[5] Sorby, S., Baartmans, B. J., 2000. The development and assessment of a course for enhancing the 3-D spatial visualization skills of first year engineering students. Journal of Engineering Education, 89(3), 301-307.

[6] Sorby, S. A., Baartmans, B. J., 2003. A Course for Development of 3D Spatial Visualization Skills. Engineering Design Graphics Journal, 60(1), 13-20.

[7] Newman, E.L., Caplan, J.B., Kirschen, M.P., Korolev, I.O., Sekuler, R., Kahana, M. J., 2007. Learning your way around town: how virtual taxicab drivers learn to use both layout and land- mark information. Cognition, 104, 231–253.

[8] Inagaki, H., Meguro, K., Shimada, M., Ishizaki, J., Okuzumi, H., Yamadori, A., 2002. Discrepancy between mental rota¬tion and perspective-taking abilities in normal aging as¬sessed by Piaget's Three-mountain task. Journal of Clinical and Experimental Neuropsychology, 24, 18-25.

[9] Hegarty, M., Waller, D., 2004. A dissociation between mental rotation and perspective-taking spatial abilities. Intelligence, 32, 175–191.

[10] Hegarty, M., Kozhevnikov, M., Waller, D., 2004. Spatial Orientation Test. University of California.

[11] Levine, M., Jankovic, I. N., Palij, M., 1982. Principles of spatial problem solving. Journal of Experimental Psychology: General, 111, 157-175.

[12] Kozhevnikov, M., Hegarty, M., 2001. A dissociation between object-manipulation and perspective taking spatial abilities. Memory & Cognition, 29, 745-756.

[13] Byrne, P., Becker, S., Burgess, N., 2007. Remembering the past and imagining the future: a neural model of spatial memory and imagery. Psychological Review, 114, 340–375.

[14] Nori, R., Giusberti, F., 2003. Cognitive styles: errors in directional judgments. Perception, 32, 307–320.

[15] Nori, R., Grandicelli, S., Giusberti, F., 2006. Alignment effect: primary –secondary learning and cognitive styles. Perception, 35, 1233–1249.

[16] Valiquette, C. M., McNamara, T. P., Smith, K., 2003. Locomotion, incidental learning, and the selection of spatial reference systems. Memory & Cognition, 31: 479–489.

[17] Presson, C. C., Hazelrigg, M. D., 1984. Building spatial representations through primary and secondary learning. Journal of Experimental Psychology: Learning, Memory, and Cognition, 10, 716–722.

[18] Richardson, A. E., Montello, D. R., Hegarty, M., 1999. Spatial knowledge acquisition from maps and from navigation in real and virtual environments. Memory & Cognition, 27, 741–750.

[19] Piccardi, L., Risetti, M., Nori, R., Tanzilli, A., Bernardi, L., Guariglia, C., 2011. Perspective changing in primary and secondary learning: A gender difference study. Learning and Individual Differences, 21, 114-118.

[20] Nori, R., Piccardi, L., Guidazzoli, F., De Luca, D., Giusberti, F., 2015. Perspective changing in WalCT and VR-WalCT: A gender difference study. Computers in Human Behavior, 53, 316-323.

[21] Nori, R., Giusberti, F., 2006. Predicting cognitive styles from spatial abilities. American Journal of Psychology, 119, 67–86.

[22] Siegel, A. W., White, S. H. (1975). The development of spatial representations of large-scale environments. In H. W. Reese (Ed.), Advances in child development and behavior (pp. 9–55). New York: Academic Press.

[23] Pazzaglia, F., De Beni, R., 2001. Strategies of processing spatial information in survey and landmark-centred individuals. European Journal of Cognitive Psychology, 13(4), 493-508

[24] Boccia, M., Piccardi, L., Di Marco, M., Pizzamiglio, L., Guariglia, C., 2016. Does field independence predict visuo-spatial abilities underpinning human navigation? Behavioural evidence. Experimental Brain Research, 234, 2799–807.

[25] Boccia, M., Piccardi, L., D'Alessandro, A., Nori, R., Guariglia, C., 2017 Restructuring the navigational field: individual predisposition towards field independence predicts preferred navigational strategy. Experimental Brain Research, 235, 1741–1748.

[26] Boccia, M., Vecchione, F., Piccardi, L., Guariglia, C., 2017 Effect of Cognitive Style on Learning and Retrieval of Navigational Environments. Frontiers in Pharmacology, 8,496.

[27] Tascón, L., Boccia, M., Piccardi, L., Cimadevilla, J.M., 2017. Differences in Spatial Memory Recognition Due to Cognitive Style. Frontiers in Pharmacology, 8, 550.

[28] Pazzaglia, F., De Beni, R., 2006. Are people with high and low mental rotation abilities differently susceptible to the alignment effect? Perception, 35, 369–383.

[29] Piccardi, L., Bocchi, A., Palmiero, M., Verde, P., Nori, R., 2017. Mental imagery skills predict the ability in performing environmental directional judgements. Experimental Brain Research, 235, 2225-2233.

[30] Méndez, M., Arias, N., Menéndez, J.R., Villar, J.R., Neira, A., Romano, P.V., Núñez, J.C., Arias, J.L., 2012. Pre-University Tuition in Science and Technology can Influence Executive Functions. Electronic Journal of Research in Educational Psychology, 12(3), 747-762.

[31] Kinsey, B., 2003. Design of a CAD integrated physical model rotator [online]. Annual conference & exposition engineering education, Nashville, Tennessee. American Society of Engineering Education. 2003. Available from: http://www.ni.com/academic/journal_asee.htm [Accessed 12 June 2010].

[32] Hsi, S., Linn, M. C., Bell, J. E., 1997. The role of spatial reasoning in engineering and the design of spatial instruction. Journal of Engineering Education, 86, 151–158.

[33] Blasko, D. G., Holliday-Darr, K.A., 2010. Longitudinal analysis of spatial skills training in engineering graphics. Proc., 65th Midyear Meeting of the Engineering Design Graphics Division of the American Society for Engineering Education, Houghton, MI, 138–151.

[34] Newcombe, N. S., 2016. Picture this: Increasing math and science learning by improving spatial thinking. Current Opinion in Behavioral Sciences, 10:1–6.

[35] Uttal, D. H., Cohen, C. A., 2012. Spatial thinking and STEM education: When, why and how. Psychology of Learning and Motivation, 57, 147–181.

[36] Uttal, D. H., Meadow, N.G., Tipton, E., Hand, L.L., Alden, A.R., Warren, C., Newcombe, N. S., 2012. The malleability of spatial skills: A meta-analysis of training studies. Psychological Bulletin, 139(2), 352–402.

[37] Ha, O., Fang, N., 2016. Spatial Ability in Learning Engineering Mechanics: Critical Review.

Journal of Professional Issues in Engineering Education and Practice, 142(2), 10.1061/(ASCE)EI.1943-5541.0000266, 04015014.

[38] Just, M. A., Carpenter, P. (1985). Cognitive coordinate systems: Accounts of mental rotation and individual differences in spatial ability. Psychological Review, 92, 137–172.

[39] Verde, P., Piccardi, L., Bianchini, F., Trivelloni, P., Guariglia, C., Tomao, E., 2013. Gender effects on mental rotation in pilots vs nonpilots. Aviation, Space, and Environmental Medicine, 84, 726–729.

[40] Sorby, S., Casey, B., Veurink, N., Dulaney, A., 2013. The role of spatial training in improving spatial and calculus performance in engineering students. Learning and Individual Differences, 26, 20-29.

[41] Lawton, C. A., 2010. Gender, spatial abilities, and wayfinding. In J. Chrisler and D. McCreary (Eds.), Handbook of Gender Research in Psychology, (New York, NY: Springer), pp. 317-341.

[42] Verde, P., Piccardi, L., Bianchini, F., Guariglia, C., Carrozzo, P., Morgagni, F., Boccia, M., Di Fiore, G., Tomao, E., 2015. Gender differences in navigational memory: pilots vs. non Pilots. Aerospace Medicine and Human Performance, 86(2),103–111.

[43] Verde, P., Boccia, M., Colangeli, S., Barbetti, S., Nori, R., Ferlazzo, F., Piccolo, F., Vitalone, R., Lucertini, E., Piccardi, L., 2016. Domain-Specific Interference Tests on Navigational Working Memory in Military Pilots. Aerospace Medicine and Human Performance, 87(6), 528-33.

[44] Boccia, M., Verde, P., Angelino, G., Carrozzo, P., Vecchi, D., Piccardi, L., Colangeli, S., Cordellieri, P., Ferlazzo, F., Giannini, A.M., 2017. Effect of professional expertise and exposure to everyday life decision-making on moral choices. Neuroscience Letters, 654: 80-85.

[45] Bandura, A., 1997. Self-efficacy: the exercise of control. New York: Freeman.

[46] Schunk, DH., Di Benedetto, M. K., 2014. Academic self-efficacy. In Furlong M. J., Gilman R.,

Huebner E. S., Furlong M. J., Gilman, R., &Huebner, E. S. (Eds). Handbook of Positive Psychology in Schools [pp 115-130], New York: Routledge/Taylor & Francis Group.

[47] Moritz, S. E., Feltz, D. L., Fahrbach, K.R., Mack, D. E., 2000. The relation of self-efficacy measures to sport performance: a meta-analytic review. Research Quarterly for Exercise and Sport, 71, 280-94.

[48] Pickering, S. J., Gathercole, S. E., Hall, M. Lloyd, S. A., 2001. Development of memory for pattern and path: further evidence for the fractionation of visuo-spatial memory. The Quarterly Journal of Experimental Psychology, 54A: 397–420.

[49] Hagenberger, M., Johnson, P.E., Will, J., 2006. Understanding the Costs and Benefits of Using 3D Visualization Hardware in an Undergraduate Mechanics-Statics Course, 36th ASEE/IEEE Frontiers in Education Conference, S4F-9.

[50] McClurg, P., Chaille, C., 1987. Computer games: Environments for developing spatial cognition? Journal of Educational Computing Research, 3: 95–111.

[51] Okagaki, L., Frensch, P., 1994. Effects of videogame playing on measures of spatial performance: Gender effects in late adolescence. Journal of Applied Developmental Psychology,15, 33–58.

[52] De Lisi, R., Cammarano, D., 1996. Computer experience and gender differences in undergraduate mental rotation performance. Computers in Human Behavior, 12, 351–361.

[53] Duesbury, R., O'Neil, H., 1996. Effect of type of practice in a compare-aided design environment in visualizing three-dimensional objects from two-dimensional orthographic projections. Journal of Applied Psychology, 81, 249–260.

[54] Saccuzzo, D., Craig, A., Johnson, N., Larson, G., 1996. Gender differences in dynamic spatial abilities. Personality and Individual Differences, 21, 599–607.

[55] Larson, P., Rizzo, A., Buckwalter, J., Van Rooyen, A., Kratz, K., Neumann, U., Kesselman, C., Thiebaux, M., Van Der Zaag, C., 1999. Gender issues in the use of virtual environments. CyberPsychology & Behavior, 2, 113–123.

[56] Rizzo, A., Buckwalter, J., Neumann, U., Chua, C., Van Rooyen, A., Larson, P., Kratz, K., Kesselman, C., Thiebaux, M., Humphrey, L., 1999. Virtual environments for targeting cognitive processes: An overview of projects at the University of Southern California. CyberPsychology & Behavior, 2, 89–100.

[57] Roberts, J., Bell, M., 2000. Sex differences on a computerized mental rotation task disappear with computer familiarization. Perceptual and Motor Skills, 91, 1027–1034.

[58] De Lisi, R., Wolford, J., 2002. Improving children's mental rotation accuracy with computer game playing. The Journal of Genetic Psychology, 163, 272–283.

[59] Sims, V., Mayer, E., 2002. Domain specificity of spatial expertise: The case of the video game players. Applied Cognitive Psychology, 16, 97–115.

[60] Subrahmanyam, K., Greenfield, P., 1996. Effect of videogame practice on spatial skills in girls and boys. In: P. Greenfield and R. Cocking (Eds.), Interacting with video (pp. 95–114). Norwood, NJ: Ablex.

[61] Feng, J., Spence, I., Pratt, J., 2007. Playing an action video game reduces gender differences in spatial cognition. Psychological Science, 18, 850–855.

[62] O'Boyle, M.W., 1998. On the relevance of research findings in cognitive neuroscience to educational practice. Educational Psychology Review, 10(4), 397-409.

[63] Sorby, S. A., 1999. Developing 3D spatial visualization skills. Engineering Design Graphics Journal, 63(2), 21–32.

[64] Chen, W. C., Whitehead, R., 2009. Understanding physics in relation to working memory. Research in Science & Technological Education, 27(2), 151-160.

[65] Coluccia, E., Louse, G., 2004. Gender differences in spatial orientation: a review. Journal of Environmental Psychology, 24, 329–340.

[66] Sweller, J., 1994. Cognitive load theory, learning difficulty, and instructional design. Learning and Instruction, 4,295-312.

[67] Baenninger, M., Newcombe, N., 1989. The role of experience in spatial test performance: a meta-analysis. Sex Roles, 20 (5–6), 327–344.

[68] Vasta, R., Knott, J.A., Gaze, C.E., 1996. Can spatial training erase the gender differences on the water-level task?, Psychology of Women Quarterly, 20 (4), 549–67.

[69] Tufte, E.R., 2001. The visual display of quantitative information (2nd edn.). Cheshire, CT: Graphics Press.

[70] Phillips, L.M., Norris, S.P., Macnab, J.S., 2010. Visualization in mathematics, reading, and science education. Dordrecht, The Netherlands: Springer.

[71] Shoresh, N., Wong, B., 2012. Data exploration. Nature Methods, 9(1), 5.

[72] Wai, J., Lubinski, D., Benbow C. P., 2009. Spatial Ability for STEM Domains: Aligning Over 50 Years of Cumulative Psychological Knowledge Solidifies Its Importance. Journal of Educational Psychology, 101, 817–835.

[73] Nazareth, A., Huang, X., Voyer, D., Newcombe, N., 2019, A meta-analysis of sex differences in human navigation skills. Psychonomic Bulletin & Review, https://doi.org/10.3758/s13423-019-01633-6.

[74] Hegarty, M. Crookes, R.D., Dara-Abrams, D., Shipley, T.F., 2010, Do all science disciplines rely on spatial abilities? Preliminary evidence from self-report questionnaires. In Hölscher, C. et al. (Eds.). Spatial Cognition VII, LNAI, 6222, pp. 85-94 Springer-Verlag Berlin Heidelberg.