ISSN: 1139-613X

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EFFECTIVENESS OF SPATIAL TRAINING IN ELEMENTARY AND SECONDARY SCHOOL: EVERYONE LEARNS

EFICACIA DEL ENTRENAMIENTO ESPACIAL EN PRIMARIA Y SECUNDARIA: TODOS APRENDEN

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DOI: 10.5944/educXX1.30100

Cómo referenciar este artículo/How to reference this article:

Rodán, A., Montoro, P.R., Martínez-Molina, A. & Contreras, M.J. (2022). Effectiveness of spatial training in elementary and secondary school: everyone learns. *Educación XX1, 25*(1), 381-406. https://doi.org/10.5944/educXX1.30100

Rodán, A., Montoro, P.R., Martínez-Molina, A. y Contreras, M.J. (2022). Eficacia del entrenamiento espacial en primaria y secundaria: todos aprenden. *Educación XX1, 25*(1), 381-406. https://doi.org/10.5944/educXX1.30100

ABSTRACT

Visuospatial processing is key to achieve optimal performance in academic activities, among others. In the field of spatial cognition, it has been found that practice with spatial tasks can reduce the gender gap in this type of reasoning. However, an increase in spatial scores does not always compensate the differences that exist between participants with greater and lesser spatial abilities. According to previous studies on individual differences and malleability in spatial cognition, comparable studies are needed in children and adolescents using the same evaluation and training method. In this work, the evolution profiles across three sessions of a mental rotation (MR) training of 39 students from Primary Education (study 1: 17 boys and 22 girls) and 21 from Secondary Education (study 2: 11 boys and 10 girls) were analyzed, as well as the degree of improvement obtained based on their initial spatial performance, analyzing the gender factor. In both groups, a spatial intervention (Mental Rotation Training Program) was applied during three consecutive sessions with an average duration of 35 minutes per session. For both age groups, participants with a low spatial level benefited at a similar rate as those participants with more spatial resources. This result was replicated for both genders. This research will serve as a starting point to promote and implement adaptive and personalized training, and thus be able to help those with less spatial skills. These types of interventions would become more effective and could maximize educational potential among the most disadvantaged groups.

KEYWORDS

Mental rotation, Training, Gender Differences, Achievement gains, Educational Strategies

RESUMEN

El procesamiento visoespacial es clave para lograr, entre otros, un rendimiento óptimo en actividades académicas. En el ámbito de la cognición espacial se ha encontrado que la práctica con tareas espaciales puede reducir la brecha de género en este tipo de razonamiento. Sin embargo, no siempre un aumento de las puntuaciones espaciales llega a compensar las diferencias que existen entre participantes con mayores y menores habilidades espaciales. De acuerdo con estudios previos sobre diferencias individuales y maleabilidad en cognición espacial, se necesitan estudios comparables en niños, niñas y adolescentes utilizando el mismo método de evaluación y entrenamiento. En este trabajo se analiza, en 39 estudiantes de Educación Primaria (estudio 1: 17 niños y 22 niñas) y en 21 de Educación Secundaria (estudio 2: 11 chicos y 10 chicas), el perfil de evolución a través de las diferentes sesiones de un entrenamiento en rotación mental (RM), así como el grado de mejora producido en función de su capacidad espacial de partida, analizando el factor género. En ambos grupos, se aplicó un entrenamiento espacial (Programa de Entrenamiento en Rotación Mental) durante tres sesiones consecutivas con una duración promedio de 35 minutos por sesión. Para ambos grupos de edad, los participantes con bajo nivel espacial se beneficiaron en una proporción similar que aquellos participantes con más recursos espaciales. Este resultado se replicó para ambos sexos. Esta investigación servirá como punto de partida para promover e implementar entrenamientos adaptativos y personalizados, y así poder ayudar a los que menos capacidades espaciales tienen. Este tipo de intervenciones ganarían en eficacia y podrían maximizar el potencial educativo en los grupos más desfavorecidos.

PALABRAS CLAVE

Rotación Mental, Entrenamiento, Diferencias de género, Ganancias de ejecución, Estrategias Educativas

INTRODUCTION

Spatial content is usually present in academic areas related to science, technology, engineering, or mathematics, so that visuospatial skills can predict success in these disciplines to a certain extent (Humphreys, Lubinski, & Yao, 1993). Some meta-analyzes have shown that visuospatial training can improve the performance of this skill (e.g., Uttal et al., 2013). Researchers linked to the area of education have incorporated spatial interventions into the classroom so that these skills can “permeate” into academic disciplines such as mathematics (e.g., Hawes et al., 2017; Lowrie et al., 2017).

Some interventions to improve cognitive functions have analyzed the gains produced after training based on initial abilities, finding greater benefits in those individuals with lower levels of working memory (Karbach et al., 2015) and reading performance in schoolchildren (García -Madruga et al., 2013), or in divided attention in adults (Baniqued et al., 2014).

Interventions focused on spatial cognition, more specifically on Mental Rotation (MR), have shown differences in performance in favor of males (e.g., Linn & Petersen, 1985). However, practice with spatial tasks can minimize the gender gap by equalizing this ability across both genders after training in schoolchildren (De Lisi & Wolford, 2002; Ehrlich et al., 2006), adolescents (Neubauer et al., 2010) and university students (Cherney et al., 2014).

Fernández-Méndez et al. (2020) analyzed the differential gains according to starting spatial level among 3- and 5-year-old preschoolers. Participants with a poorer initial ability showed a greater increase in their MR ability after training only the 5-year-old group. Studies have also been carried out with adolescents on the effects of training according to individual starting differences, finding disparate results. David (2012) studied 14-year-old students who played video games related to MR, Visualization (Vz) and spatial relationships and found that students with low initial scores significantly improved their MR performance compared to those with better initial skills after playing video games. However, the author did not find any gender effect, nor any interaction between baseline and gender. The findings of Bergner and Neubauer (2011) among 15-year-old students with high abilities in visuospatial aptitude suggested that the group of girls with a lower spatial performance improved more in the accuracy of the task after training, although not in Response Times (RT). In the context of cognitive deficits, Wiedenbauer and Jansen-Osmann (2007) found that boys and girls aged between 8 and 14 years diagnosed with spina bifida benefited considerably from training, improving their RT and their success ratio in a computerized MR task, equaling the performance of healthy children.

Individual differences in MR have also been analyzed in adults, with training through the *Tetris* video game, finding disparate results. While some authors have seen that inexperienced players benefit as much as expert players in this video game (Sims & Mayer, 2002), others have found that those with worse initial skills yielded higher increases, equaling in the last sessions those with high spatial skills (Terlecki et al., 2008). Another study by Contreras et al. (2018) also found that university students with lower initial skills in Vz improved significantly more compared to their peers with better initial skills.

In summary, although most studies point towards a more pronounced improvement after training in those participants who initially exhibit lower initial spatial ability, there are studies that have found that participants with better or worse level benefit equally from spatial training. On the other hand, an influential meta-analysis, which has confirmed the malleability of spatial skills, highlights the lack of research at various ages with a similar training method in order to obtain comparable results (see Uttal et al., 2013, for a review). Given the scarce literature on studies that analyze individual performance with MR tasks, we aim to search for more evidence using for the first time an analogous method in evaluation and training across two educational stages that are crucial, Primary (childhood) and Secondary (adolescence). Encouraging spatial reasoning in Primary Education could be key for boys and girls to reach an optimal level of visuospatial reasoning in later stages, such as adolescence, in which students must determine which academic path they wish to follow, this being crucial for their future career. Therefore, educational interventions of a spatial nature that take place before or during adolescence could be relevant, especially when the presence of women is scarce in STEM (Science, Technology, Engineering and Mathematics) careers, where spatial reasoning seems to play an important role.

Objectives and hypotheses

The objective of the two studies (Primary and Secondary students) of the present work was to analyze the progress over three training sessions in an MR task, as well as the performance as a function of a high or low spatial ability, measured in the criterion test applied, and verifying that the two groups were comparable in general intelligence. Participants with a lower baseline ability in the spatial test were expected to achieve a similar level after training as those starting from a higher level. The performance was evaluated through measures of success (correct answers, CA) ratio and response time (RT) for each of the sessions of the task. The two studies carried out with 39 primary school students and 21 secondary school students are shown below, belonging only to the groups that underwent MR training (EG, hereinafter). The results related to the pre-test and post-test differences, as well as the improvements exhibited in spatial ability after training in the experimental and control groups can be seen in Rodán et al. (2019) for the primary school group, and in Rodán et al. (2016) for the high school group.

STUDY 1

Method

Participants

In this study, 39 students (*M* = 7.68 years, *SD* = 0.66; 17 boys and 22 girls) in second year of Primary Education from two public schools ("CEIP Escuelas Aguirre" and "CEIP Leopoldo Alas"), located in a central area of Madrid, with a medium-high sociocultural level, took part. These were students belonging to the EG of a previous study, where performance was compared between a trained group (EG) and another untrained control group (CG, hereinafter) (Rodán et al., 2019).

Materials

Raven's Progressive Matrices (SPM version; Raven, Court, & Raven, 1996)

This test evaluates general intelligence from the age of 6. The test consists of 60 exercises divided into 5 series with 12 elements each, and it is executed without a time limit, although the average duration of the test is 40-90 minutes. Each slide has 6 or 8 answer options, with only one correct answer. The maximum possible score is 60 points. The split-half reliability is .90, while the test-retest ranges between .83 and .90 (Seisdedos, 1995).

EFAI-1 spatial aptitude test "E"

It is a subtest of the Factorial Assessment of Intellectual Aptitudes battery (Santamaría et al., 2005), validated for 7- to 10-year-olds. It evaluates the ability to mentally imagine movements and transformations of an object in space. It is considered an approximation to the visual processing factor, "*Gv*" –Lohman, 1996– (p. 17). It has 30 exercises with four response options each, in which the participant must decide which of the four response stimuli fits as a puzzle into a reference target by rotating them. The duration of the test is six minutes, and the maximum score is 30 points. The reliability of this test is .86 (see an example of an item in Rodán et al., 2019).

Mental Rotation Training Program (PERM-Programa de Entrenamiento de Rotación Mental, in Spanish)

The PERM is composed of 480 tests, and each one consists of a white mold on a gray box (reference target) located on the left side of the screen, and two two-dimensional figures located on the right, numbered as "1" and "2", shaped identical to the mold. The PERM's task is to imagine transformations and rotations, deciding which of the two stimuli "1" or "2" matches the mold if it is rotated. Only one of the two stimuli fits inside the mold (Figure 1).

The intra- and inter-session difficulty of the task was manipulated according to the characteristics of the stimuli - close and concrete figures or abstract figures - and the number of difficult trials increased as sessions progressed. During the execution of PERM, the participant had to answer each of the trials, so that the program recorded 450 trials of the 480 that were presented (the first 10 trials of each session were used as familiarization with the task). In each session, the correct answers (hits) and response times for each trial were computed. The *E-Prime version 1.2* computer software (Psychology Software Tools, 2002) was used for the programming, presentation of stimuli and data collection of the PERM task (for additional information on PERM, see Rodán et al., 2019).

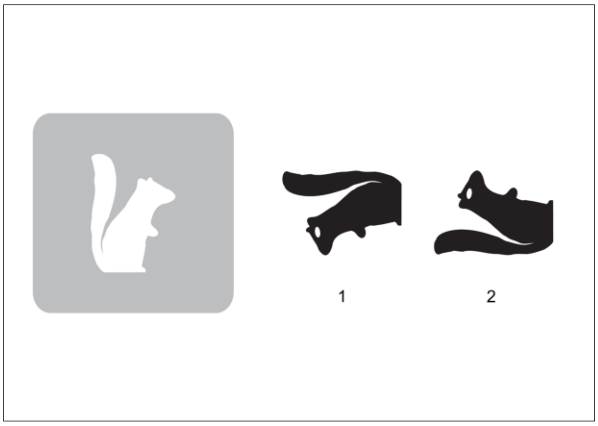

Figure 1. Example of a trial used in PERM in Study 1

Procedure

The tests were administered on consecutive days, with one session per day, for a total period of five days (one day for the pre-test, three days of training and one day for the post-test).

On the first day (pre-test phase), the Raven's Progressive Matrices were administered collectively first and then the EFAI-1, with a five-minute break between the two. It was carried out in the students' usual classroom with four examiners, and the tables were organized individually.

For the next three days, each participant performed the training task (PERM) individually on a computer in three consecutive sessions. After the 10 pre-training trials, the 150 trials of the task itself were carried out, divided into two blocks of 75 presentations, with a 5-minute break between both blocks. The experimenters stressed the importance of precision throughout the training, insisting that they could take all the time necessary to ensure a correct answer. All trials had to be answered in a forced way as the possibility of blank answers was not contemplated. The number of trials per session presented in PERM was 5850 (150 trials x 39 participants). -After eliminating certain trials due to premature answers or excess time consumed, a total of 5723 (97.8%), 5656 (96.7%) and 5655 (96.7%) trials were analyzed in Sessions S1, S2 and S3, respectively. After eliminating these trials, the minimum performance times were 311.4 sec. (5.19 min.), 335.4 sec. (5.59 min.) and 223.2 sec. (3.72 min.). Whereas, the maximum performance time was 1176 sec. (19.6 min.), 1416 sec. (23.6 min.) and 1290 sec. (21.5 min.) for S1, S2 and S3, respectively.

Finally, on the last day (post-test phase), the Raven Progressive Matrices and EFAI-1 tests were administered under the same conditions as in the pre-test phase.

The legal guardians of the children signed an informed consent, according to the Declaration of Helsinki, complying with the data protection regulations and the approval of the Ethics Committee of the UNED.

Data Analyses

To confirm that the groups were comparable in intelligence according to the level of spatial ability (high: "↑ SA"; low: "↓ SA"), and in both genders, a one-factor ANOVA was performed for the measure obtained in the Raven in the pretest phase. To examine the evolution profile through the different training sessions as a function of SA level and gender, a mixed 2 × 2 × 2 repeated measures ANOVA was carried out with "SA level" (low, high) and "Gender" (boys, girls) as inter-subjects factors, and with repeated measures "Session" (Session 1, Session 2 and Session 3) as intra-subjects factor. This analysis was applied to the dependent variables "proportion of correct answers" (number of correct answers/total trials in each session) and "response time" (time between the presentation of the trial and the correct answer), in the training phase.

Finally, to analyze the gains obtained in spatial ability (EFAI-E) as a function of SA level and gender, a 2 × 2 × 2 repeated measures ANOVA was carried out with "SA level" (low, high) and "Gender" (boys, girls), as inter-subjects factors, and with "pre-post repeated measures" (pre-test, post-test) as intra-subjects factor.

Statistical analyzes were performed with the *SPSS statistical software, version 24.0* (IBM Corp., 2016) with a significance level of .05.

Results

Preliminary Analyses

Preliminary analyses showed that both groups (↓ SA and ↑ SA) did not differ in their scores on the intelligence test of the pretest phase. No gender differences were found for the entire group, nor for the interaction between group and gender factors.

Performance during PERM and gains obtained in MR skill

The level of SA (↓ SA and ↑ SA) of the participants was determined according to the skills observed in the spatial test (EFAI-E) in the pretest phase, using the median as a cut-off point, which in this study was 9 points.

In the PERM performance analysis, all trials with RTs less than 500 ms (Wiedenbauer & Jansen-Osmann, 2007), and RTs greater than 60 seconds were excluded for all participants, so that 516 trials (2.94% of the total) were finally eliminated. The average RT (in seconds) for each participant was calculated only for the correct answers following the same procedure used in classical reference studies for the analysis of performance in Mental Rotation tasks (Shepard & Metzler, 1971; Voyer & Jansen, 2016).

Table 1 shows the descriptive analyses of the proportion of correct answers and of the RTs of the correct trials. The mixed ANOVA 2 (Gender) x 2 (SA level) for the proportion of correct answers revealed a main effect of the SA level in Session 1 F (1, 35) = 5.67, MSE = .073, p = .023, η^2_p = .14], in Session 3 [F (1, 35) = 4.251, MSE = .068, p = .047, η^2_p = .11], and for the total of all sessions [F (1, 35) = 4.19, MSE = .050, p = .048, η^2_p = .11], so that participants with ↑ SA obtained a higher proportion of correct answers in these three conditions: [CA-S1:↓SA: M = 0.78, ↑SA: M = 0.87, mean difference = 0.09, p = .02], [CA-S3: ↓SA: M = 0.72, ↑SA: M = 0.80, mean difference = 0.08, p = .04], [CA-TOTAL: ↓SA: M = 0.75, ↑SA: M = 0.82, mean difference = 0.07, p = .04]. No other main effects or interactions between factors were found. The repeated measures ANOVA 3 (Session) x 2 (gender) x 2 (SA level) only showed a significant effect in the Session factor [F (2, 70) = 18.9, MSE = .056, p < .001, η^2_p = .35]. The proportion of correct answers progressively decreased from S1 to S3, and the pairwise comparisons showed a higher proportion of correct answers in S1 compared to S2 and S3 [S1: M = 0.83; S2: M = 0.76; S3: M = 0.76; mean difference S1-S2 = 0.06, p < .001; mean difference S1-S3 = 0.07, p < .001]. No significant interactions between factors were found for this variable. The RT analysis only showed a significant interaction between the factors Gender x SA level for Session 2 [F (1, 35) = 7.08, MSE = 11432, p = .01, η^2_p = .17] and for the total of all sessions [F (1, 35) = 4.53, MSE = 4249, p = .040, η^2_p = .12], which was explained by longer RTs in girls in the ↑ SA group

[RT- S2 (↑ SA): boys: *M* = 4.2 sec.; girls: *M* = 6.0 sec.; mean difference = 1.8 sec., p <.01], [RT-TOTAL (↑ SA): boys: *M* = 4.4 sec; girls: *M* = 5.6 sec.; mean difference = 1.2 sec., p = .01]. A marginal effect of the Gender factor was also observed in Session 3 [F (1, 35) = 4.05, *MSE* = 8997, p = .052, $\eta^2{}_p$ = .10], due to the shorter RTs in boys than in girls (boys: *M* = 4.7 sec.; girls: *M* = 5.6 sec.; mean difference = 0.9 sec., p = .052). No other main effects or interactions between factors were found. The repeated measures ANOVA 3 (Session) 2 (Gender) x 2 (SA level) did not show any main effect or interactions between factors. Figure 2 shows the performance through the different training sessions in Primary students.

Table 1
Descriptive statistics (means and standard deviations) of the proportion of correct answers and RTs of correct trials (in seconds) for each session and for the total of the three sessions of PERM in Primary school students.

	Total (N = 39)			
	↓SA (n = 20)		↑SA (n = 19)	
Measures	Boys (n = 9)	Girls (n = 11)	Boys (n = 8)	Girls (n = 11)
	M (SD)	M (SD)	M (SD)	M (SD)
CA-S1	0.78 (0.13)	0.79 (0.15)	0.86 (0.06)	0.88 (0.08)
CA -S2	0.71 (0.13)	0.77 (0.12)	0.76 (0.12)	0.82 (0.10)
CA -S3	0.69 (0.15)	0.74 (0.13)	0.79 (0.11)	0.81 (0.11)
CA-TOTAL	0.73 (0.13)	0.77 (0.13)	0.80 (0.09)	0.84 (0.09)
RT-S1	5.2 (1.3)	4.6 (1.1)	4.6 (0.6)	5.1 (0.9)
RT-S2	5.4 (0.8)	5.0 (1.3)	4.2 (0.8)	6.0 (1.8)
RT-S3	4.8 (1.5)	5.5 (2.0)	4.5 (0.7)	5.8 (1.2)
RT-TOTAL	5.2 (0.7)	5.0 (1.3)	4.4 (0.6)	5.6 (1.0)

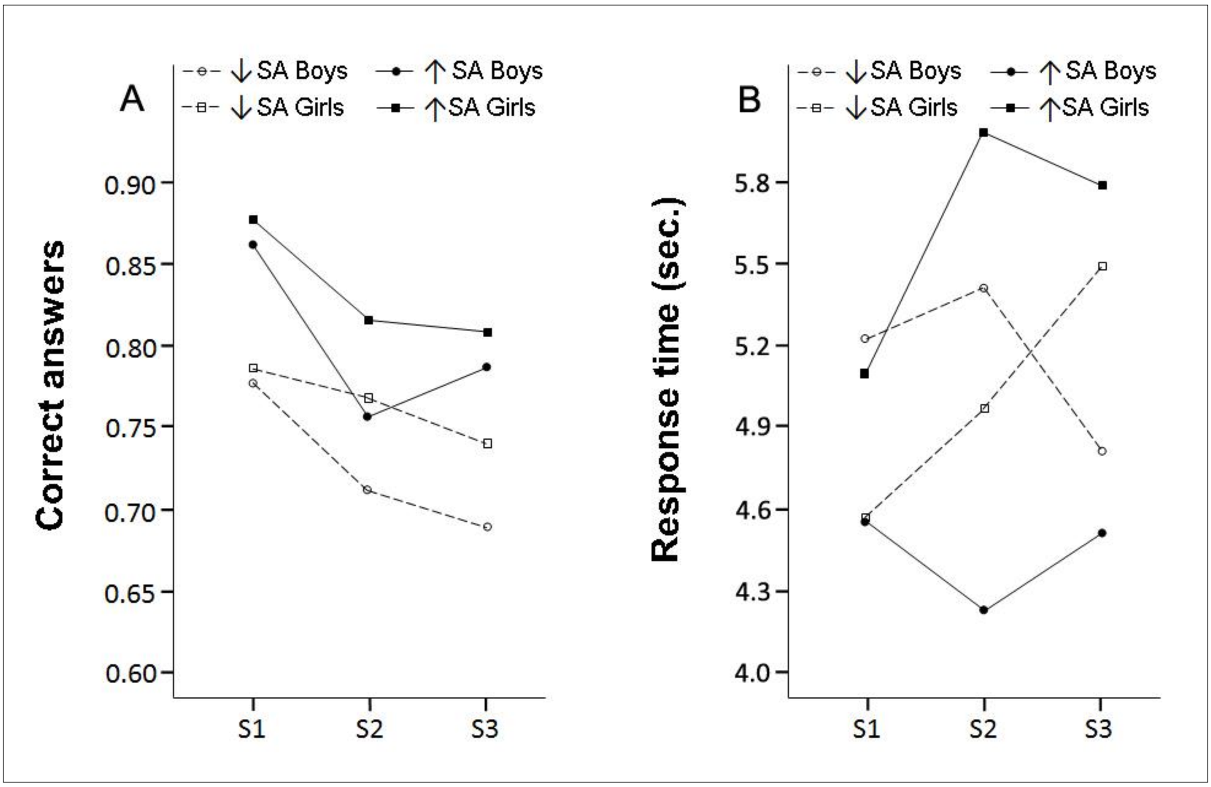

Figure 2. Proportion of correct answers (A) and response times of correct trials (B) for the interaction Sessions 1 to 3 x gender x level of spatial ability in Primary students

Table 2 shows the descriptive analyses of the scores obtained in the EFAI-E for both genderds and according to the spatial ability level. The repeated measures ANOVA 2 (pre-post) 2 (Gender) x 2 (SA level) for the dependent variable "EFAI-E", only showed a main effect on the pre-post factor [F (1, 35) = 79.1, MSE = 827, p < .001, η^2_p = .69], thus explaining a general gain in MR ability. No other significant interactions between factors were found.

Tabla 2
Descriptive statistics (means and standard deviations) of the scores obtained in the EFAI-E for both genders of the group of Primary participants with low and high level of spatial ability.

	↓SA (n = 20)		
EFAI-E (max. = 30)	**Boys (n = 9)**	**Girls (n = 11)**	**TOTAL**
	M (SD)	**M (SD)**	**M (SD)**
Pretest	6.33 (1.32)	6.73 (1.68)	6.55 (1.50)
Post-test	14.4 (5.13)	13.3 (4.59)	13.8 (4.74)
Increment	8.11 (4.70)	6.55 (4.80)	7.25 (4.70)
	↑SA (n = 19)		
EFAI-E (max. = 30)	**Boys (n = 8)**	**Girls (n = 11)**	**TOTAL**
	M (SD)	**M (SD)**	**M (SD)**
Pretest	13.6 (3.82)	12.0 (3.13)	12.7 (3.43)
Post-test	20.6 (3.38)	16.6 (5.59)	18.3 (5.09)
Increment	7.00 (3.93)	4.64 (4.65)	5.63 (4.41)

Discussion

The objective of this study was to examine the individual differences in performance across the different sessions of an MR training program, as well as the differential gains as a function of the starting spatial level in schoolchildren in 2nd year of Primary Education.

The results relative to the proportion of correct answers showed, in general (global scores of the three sessions), that the proportion of correct answers was higher in the group of participants with greater spatial ability (↓SA = 0.75 vs. ↑SA = 0.82). In any case, no interaction was obtained between the time of evaluation and the level of spatial ability, suggesting that both groups had a similar performance throughout the three sessions. Moreover, both boys and girls had a comparable performance in the proportion of correct answers throughout the entire training program, thus, no interaction was found between the factors of Session and Gender (boys = 0.77 vs. girls = 0.80). It is interesting to mention that the proportion of correct answers progressively and significantly decreased from the first to the third session, in both groups according to the level of spatial ability, and also in both genders, possibly due to the progressive increase in the level of difficulty of the task in each of the sessions.

No significant differences were found in the RTs of both groups according to initial spatial ability (↓SA = 5.1 sec. vs. ↑SA = 5.0 sec.), or as a function of gender (boys = 4.8 sec. vs. girls = 5.3 sec.). This result could be in line with those found by Wiedenbauer and Jansen-Osmann (2008), who did not find differences in RT between boys and girls aged 10 and 11 years. However, the analyses showed that the girls with better spatial skills were the ones who needed the most time to respond (RTs significantly higher than the rest of the groups).

In studies on gender differences in spatial abilities, certain discrepancies have been found. Some studies argue that spatial interventions minimize gender differences (see Linn & Hyde, 1989, for a review), while others find that the gender gap in spatial performance does not narrow (Baenninger & Newcombe, 1989). Our results are congruent with those of studies carried out in schoolchildren where it has been observed that both genders benefit to the same extent after a training program in spatial reasoning (Hawes et al., 2017; Lowrie et al., 2017). Boys have shown similar increases to girls after spatial training, and this finding has also been seen in both groups according to their level of spatial ability.

STUDY 2

Method

Participants

A total of 21 students (*M* = 14.3 years, *SD* = 0.44; 11 boys and 10 girls) from 3rd year of Secondary Education of the CEU-San Pablo de Montepríncipe School (Boadilla del Monte, Madrid), with a medium-high sociocultural level, took part in this study. These students belonged to the EG of a previous study where the performance between a trained group was compared with an untrained group (Rodán et al., 2016).

Materials

Raven's progressive matrices (SPM version; Raven et al., 1996)

It is the same instrument used and described in Study 1, and its application was carried out with the same procedure.

EFAI-3 spatial aptitude test "E"

Spatial subtest from the Factorial Assessment of Intellectual Aptitudes battery (Santamaría et al., 2005) similar to that described in the Primary school study. For the study of spatial skills in this group, Level 3 was used, which is recommended for participants between 12 and 15 years of age. This level consists of 27 assessment exercises plus two practice examples (maximum 27 points). The task requires the participant to combine the rotated figure from the answer options with other pieces already placed on the *target* for the puzzle to be completed. The time for this test is six minutes. The studies carried out by Santamaría et al. show reliability indices of .71 (Santamaría et al., 2005).

Mental Rotation Training Program (PERM)

This version of PERM consists of 330 double response trials (for a total of 660 responses or decisions). Each presentation consists of a white mold on a gray box (reference *target*) located on the left side of the screen, and two two-dimensional figures located on the right side - listed as "1" and "2" - with an identical shape to that of the mold (Figure 3). The difficulty within each session and between sessions increased, manipulating the complexity of the figures, in terms of their symmetry, number of stimuli, discontinuity, etc. The task requires the participant to mentally imagine rotations and indicate whether or not figure “1” on the right fits into the mold, and then repeat the task with figure “2”, in such a way that, to access the consecutive trial, the participant must respond to each figure, finally registering a total of 600 responses out of the 660 that are presented in the set of three sessions (the first 10 double trials of each session were for familiarization with the task). The correct responses (hits) and response times of each trial were recorded in each session (for additional information on PERM, see Rodán et al., 2016).

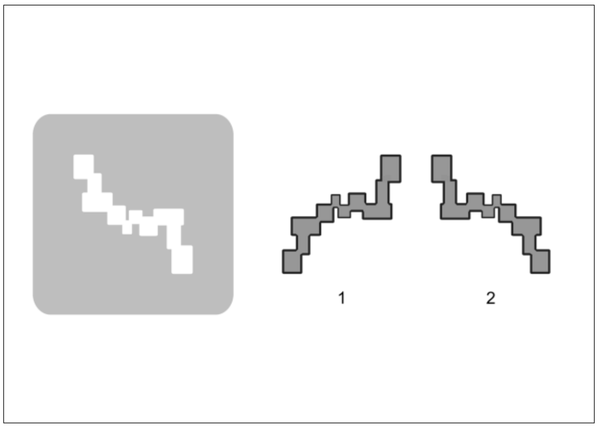

Figure 3. Example of a trial used in PERM in Study 2

Procedure

The tests were administered on five consecutive days, with one session per day, distributed in three well-differentiated phases.

The Raven Progressive Matrices and EFAI-3 tests of the pretest phase were administered collectively on the first day, on individual tables in the students' usual classroom, and supervised by three examiners. The order of the tests and the rest between them was the same as in Study 1.

The PERM training was applied individually in the computer room during three consecutive sessions, one per day. Ten practice trials were carried out to facilitate the understanding of the task. The training consisted of 100 presentations (200 decisions) in each session. The experimenters' instructions to the participants were the same as in Study 1. The number of trials per session presented in PERM was 4200 (100 trials x 2 decisions x 21 participants). After eliminating some trials due to anticipation or excess time consumed, a total of 3730 (88.8%), 3778 (90.0%) and 3672 (87.4%) were finally analyzed in sessions S1, S2 and S3, respectively. After eliminating these trials, the minimum time to perform was 162 sec. (2.70 min.), 174 sec. (2.90 min.) and 180 sec. (3.00 min.), while the maximum time was 1146 sec. (19.1 min.), 684 sec. (11.4 min.) and 660 sec. (11.0 min.) for S1, S2 and S3, respectively.

Finally, on the last day, the Raven Progressive Matrices and EFAI-3 tests were administered under the same conditions as in the pretest phase.

All the legal guardians of the participants signed an informed consent, and the study was approved by the Ethics Committee of the UNED.

Data Analyses

The analyses performed in this study were identical to those performed in Study 1.

Results

Preliminary Analyses

Both groups (↓SA and ↑SA) did not differ in intelligence in the previous phase. No gender differences were found for the whole group, nor for the interaction between Group and Gender factors.

Performance during PERM and gains obtained in MR skill

The SA level (↓SA and ↑SA) of the EG boys and girls was determined according to the EFAI-E median in the pretest phase, which in this case was also 9 points. Using the same criteria as in Study 1, a total of 1420 trials (11.3% of the total) were finally excluded. The average RT in seconds was calculated for each participant only for the correct answers.

Table 3 shows the descriptive analyses of the proportion of correct answers and the RTs of the correct trials. In relation to the proportion of correct answers in each of the three sessions (S1, S2, S3) and for the total sessions (TOTAL), the mixed ANOVA 2 (Gender) x 2 (SA level) revealed a main effect of Gender in Session 1 [F (1, 17) = 5.02, MSE = .058, p = .039, η^2_p = .23], due to a higher proportion of correct answers in girls (girls M = 0.84, boys: M = 0.73, mean difference = 0.11, p = .039). Also, an effect of the SA level was seen in Session 3 F (1, 17) = 12.4, MSE = .12, p = .003, η^2_p = .42], and for the total of all sessions [F (1, 17) = 6.64, MSE = .052, p =.020, η^2_p = .28], so that, in both cases, the group of participants with high SA obtained a higher proportion of correct answers [CA-S3: ↓SA: M = 0.69, ↑SA: M = 0.84, mean difference = 0.15, p < .01; CA-TOTAL: ↓SA: M = 0.72, ↑SA: M = 0.82, mean difference = 0.10, p = .02]. The high SA group had a higher proportion of correct answers in Session 2, but only a marginal effect was found [F (1, 17) = 3.83, MSE = .032, p =.067, η^2_p = .18]. No other main effects or interactions were found. The repeated measures ANOVA 3 (Session) x 2 (Gender) x 2 (SA level) showed a significant interaction between Session x Gender factors [F (2, 34) = 8.22, MSE = .016, p = .001, η^2_p = .33], which was explained by a decrease in the proportion of correct answers from S1 to S3 in the group of girls [S1: M = 0.84; S2: M = 0.77; S3: M = 0.77; mean difference S1-S2 = 0.06, p < .01; mean difference S1-S3 = 0.07, p = .01]. A significant interaction between Session x SA level [F (2, 34) = 4.92, MSE = .010, p = .013, η^2_p = .22] was also obtained, so that only the group of participants with low SA decreased the proportion of correct answers from the first to the last session [S1: M = 0.75; S3: M = 0.69; mean difference S1-S3 = 0.05, p = .04]. No other effects or significant interactions were found for this variable. For the RTs, a marginal effect of the Gender x SA level interaction was found in Session 3 [F (1, 17) = 4.11, MSE = 4000, p = .059, η^2_p = .20], which was explained by lower RTs in boys in the low SA group and in girls in the high SA group. No other effects or significant interactions were found. The repeated measures ANOVA 3 (Session) x 2 (Gender) x 2 (SA level) showed a significant main effect of the Session factor, due to the fact that the RTs decreased from S1 to S3 F (2, 34) = 4.62, MSE = 3176, p = .017, η^2_p = .21]. Pairwise comparisons showed significantly longer RTs in S1 compared to S3 [S1: M = 5.2 seg.; S3: M = 4.4 seg.; mean difference S1-S3 = 0.8, p =

.05]. No other significant interactions were found. Figure 4 shows the performance through the different training sessions in Secondary students.

Table 3
Descriptive statistics (means and standard deviations) of the proportion of correct answers and RTs of correct trials (in seconds) for each session and for the total of the three sessions of PERM among secondary school students.

	Total (N = 21)			
	↓SA (n = 11)		↑SA (n = 10)	
Measures	Boys (n = 6)	Girls (n = 5)	Boys (n = 5)	Girls (n = 5)
	M (SD)	M (SD)	M (SD)	M (SD)
CA-S1	0.67 (0.11)	0.82 (0.05)	0.78 (0.17)	0.85 (0.06)
CA-S2	0.70 (0.07)	0.75 (0.10)	0.80 (0.13)	0.80 (0.06)
CA-S3	0.66 (0.13)	0.87 (0.07)	0.72 (0.08)	0.81 (0.08)
CA-TOTAL	0.68 (0.10)	0.76 (0.07)	0.82 (0.11)	0.82 (0.06)
RT-S1	4.8 (1.1)	6.1 (1.2)	4.9 (1.2)	4.8 (1.0)
RT-S2	4.2 (1.3)	5.3 (1.1)	4.2 (1.4)	4.8 (1.4)
RT-S3	3.5 (0.7)	5.1 (0.9)	4.6 (1.1)	4.5 (1.3)
RT-TOTAL	4.3 (0.8)	5.5 (0.9)	4.5 (0.8)	4.6 (1.0)

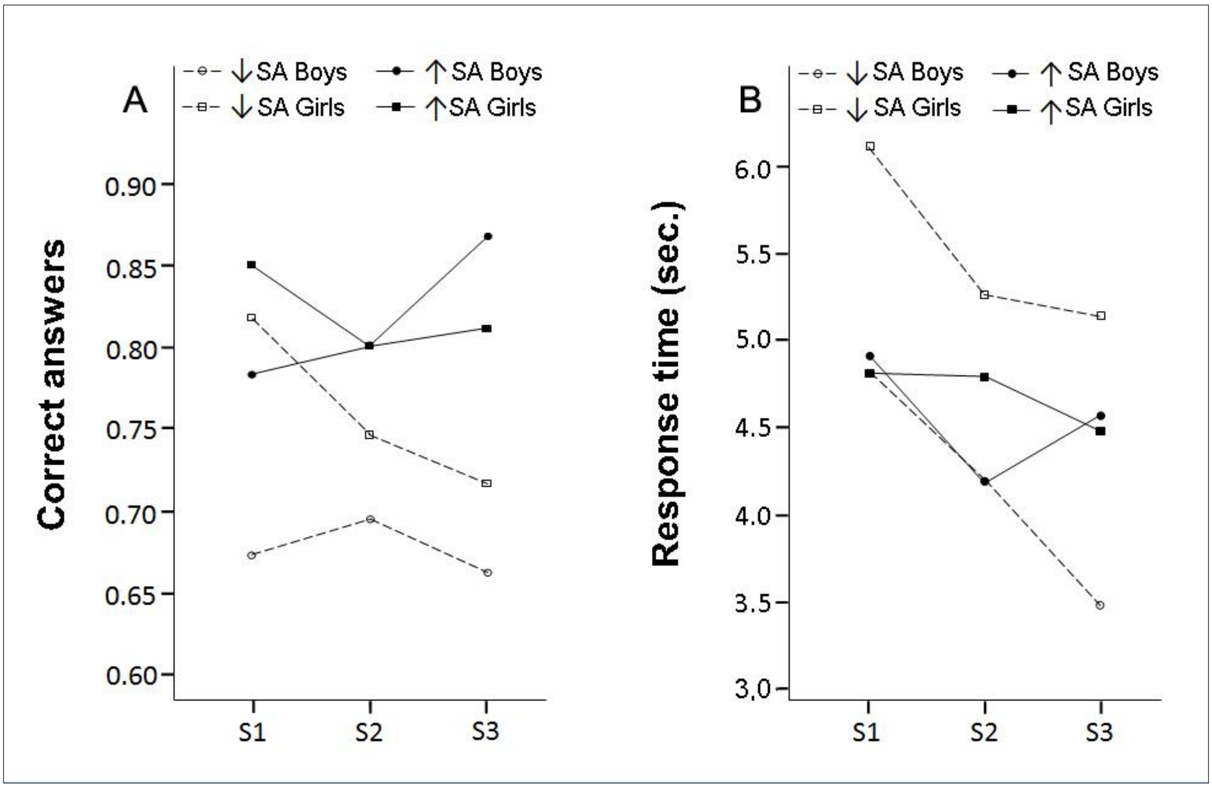

Figure 4. Proportion of correct answers (A) and response time of correct answers (B) for the interaction Sessions 1 to 3 x Gender x Spatial ability level in Secondary school students

Table 4 shows the descriptive analyses of the scores obtained in the EFAI-E in both genders and according to the level of spatial ability. The repeated measures ANOVA 2 (pre-post) x 2 (gender) x 2 (SA level) for the dependent variable “EFAI-E” showed a main effect on the time factor [F (1, 17) = 88.1, MSE = 32, p < .001, η^2_p = .84], which indicates an improvement, in general, in MR ability. No other significant interactions between factors were found.

Table 4

Descriptive statistics (means and standard deviations) of the scores obtained in the EFAI-E in both genders for the group of Secondary school participants with low and high levels of spatial ability.

	↓SA (n = 11)		
EFAI-E (max. = 30)	**Boys (n = 6)**	**Girls (n = 5)**	**TOTAL**
	M (SD)	**M (SD)**	**M (SD)**
Pretest	7.50 (1.05)	7.40 (0.89)	7.45 (0.93)
Post-test	11.5 (2.35)	12.4 (2.30)	11.9 (2.26)
Increment	4.00 (1.67)	5.00 (2.35)	4.45 (1.97)
	↑SA (n = 10)		
EFAI-E (max. = 30)	**Boys (n = 5)**	**Girls (n = 5)**	**TOTAL**
	M (SD)	**M (SD)**	**M (SD)**
Pretest	12.8 (3.19)	12.2 (1.48)	12.5 (2.37)
Post-test	20.2 (3.03)	18.0 (1.87)	19.1 (2.64)
Increment	7.40 (3.58)	5.80 (3.03)	6.60 (3.24)

Discussion

In general, a significantly higher proportion of correct answers on PERM was found in the group of students with better ability in the spatial test “E” of the EFAI-3 compared to the group with low spatial ability. The individualized analysis of each session only showed significant differences between these groups in the last session. In addition, a time x SA level interaction was observed in the proportion of correct answers, so that the participants with high SA improved their performance from the first to the third session, while those with low SA decreased throughout the three sessions.

A higher proportion of correct answers was also observed in the group of girls for the total sample of the experimental group. However, the girls only differed significantly from the boys in the first training session. In addition, a Session x Gender interaction was found, as the group of girls experienced a significant decrease in the proportion of correct answers from the first to the last session. Another finding was that boys with high SA increased their correct answer ratio as the program progressed, although no significant gender differences were observed between high and low spatial ability groups across the different training sessions.

Although only the students with poorer spatial ability on the EFAI-3 experienced a significant decrease in RTs from the first to the last session of PERM, both groups with high and low spatial ability had a similar performance throughout training in this variable. No differences were found in the RTs of boys and girls, in line with the findings of Wiedenbauer and Jansen-Osmann (2008), who also did not see a gender effect in response times in an MR task in schoolchildren.

Our results in the adolescent population converge with those found in other studies carried out in the same age group, which maintain that both genders benefit in a similar way after a training program in spatial reasoning (Neubauer et al., 2010; Samsudin et al., 2011; Sanz de Acedo Lizarraga & García Ganuza, 2003). Regarding the gains obtained with training, our study is convergent with other studies that did not find differential gains according to the starting level in interventions with 3-year-old preschoolers (Fernández-Méndez et al., 2020) or with university adults (Sims & Mayer, 2002).

GENERAL DISCUSSION AND CONCLUSIONS

Any intervention on spatial skills that occurs before or during adolescence could be crucial, especially when the presence of people with fewer spatial resources (including women) is scarce in certain university degrees related to science, technology, engineering and mathematics. Therefore, and according to what was suggested by Uttal et al. (2013) in their influential meta-analysis on malleability of spatial skills, we carried out a study using an analogous method across two different age groups -primary and secondary-, both for the pre-post evaluation, and for MR training, to thus be able to compare the results obtained over three training sessions. The objective of the present two studies was to analyze the performance of the task throughout a training in MR using PERM, examining the performance of the participants by gender and by levels of spatial ability (low and high SA in the spatial aptitude test "E" of EFAI-3). Also, the differential gains produced after training were assessed according to gender and starting spatial level. Based on the previous literature, we expected that participants with lower initial spatial skills would experience greater gains until reaching a similar level after training to those participants with higher spatial resources.

In general (global scores of the three sessions), there were only differences in the proportion of correct answers, so that it was lower in participants with low SA. However, students with “low” SA performed well, reaching a ratio of correct answers through the three training sessions of 0.75 and 0.72, in primary and secondary students, respectively. In any case, these results differ significantly from those obtained by participants with high spatial skills (0.82 in trained primary and secondary students).

The evolution analyses throughout the three sessions also showed certain points of convergence and divergence between the two age groups. In the group of schoolchildren, the proportion of correct answers declined significantly, and their responses were slower from the first to the last session, although we cannot conclude if these results were due to the increase in the difficulty of the task as the training program progressed or to a lack of motivation. In any case, in general, the level of correct answers in schoolchildren was good (0.83 in Session 1; 0.76 in Session 3). However, in the adolescent group, RTs significantly decreased from the first session (5.2 sec.) to the last (4.4 sec.), keeping their correct answer ratio practically constant throughout the three sessions (≈ 0.77). This could indicate that, despite the increase in the difficulty of the task as sessions progressed, their level of motivation and/or their learning allowed them to respond faster and maintain an optimal level of correct answers.

The correct answer ratio profiles did show differences in both age groups, only finding variations across the three sessions by gender groups and SA in adolescents. By gender groups, the boys improved their MR ability from the first session to the last, while the girls worsened from the beginning to the end of the training program. These results could be explained because the boys were more motivated to produce correct answers throughout the different PERM sessions, similar to the results found by Voyer et al. (2004), who suggested that men seem to be more motivated by the need to produce answers, showing less response guessing behavior.

An aspect that is scarcely valued in the literature on MR training using an analogous method at different ages is that of the increases produced as a function of the initial spatial level. In the present work, similar results have been found among both age groups, so that participants with low spatial ability benefited in a similar proportion to those participants with better spatial abilities. These findings are compatible with the results of studies on gender differences in spatial skills, in which it has been observed that both genders benefit to the same extent after training in spatial reasoning, both in primary schoolchildren (Hawes et al., 2017; Lowrie et al., 2017) and in secondary school adolescents (Neubauer et al., 2010; Samsudin et al., 2011; Sanz de Acedo Lizarraga & García Ganuza, 2003). Our results also converge with those obtained in studies that have not found differential gains after spatial training according to the starting level in MR in 3-year-old preschoolers (Fernández-Méndez et al., 2020) and university adults (Sims & Mayer, 2002).

Finally, it is worth mentioning the variability in the time spent on the training task in both studies, which shows that some participants need a substantially longer time to achieve optimal performance. This is important for the design of adaptive training programs, so that, to access a higher level of difficulty, a minimum should be reached that ensures that the most basic items have been assimilated. Only in this way could this type of training be more effective and have an educational purpose, especially in those participants who have fewer resources.

Limitations of the study and future lines of research

The small number of participants in both studies, especially in secondary school (N = 21), could have affected the analyses of variance, thus caution must be taken in generalizing the conclusions obtained. In this sense, it would be desirable for future research to have a larger sample to ensure the generalization of results.

In our opinion, the training program is not lacking in intensity (450 and 600 trials in schoolchildren and adolescents, respectively), and, in general, the participants showed a high level of motivation and competitiveness with their peers to perform at their best. However, three sessions may have been insufficient to show greater increases in individuals with low spatial ability. In this sense, Terlecki et al. (2008) followed twelve weeks of spatial training, finding that participants with lower spatial abilities needed some time to show spatial gains and catch up with participants with better abilities. In future studies, the analysis of the relationship between the total time it takes to perform the task (including trials that are not correct) and the proportion of correct answers, as well as the analysis of the progression throughout the trials, would allow further knowledge regarding the profile of evolution in a student's learning, as a function of total time, when this type of training is carried out.

Despite these limitations, we believe that the present work is of interest to establish guidelines in the design of programs to improve spatial cognition, promoting and implementing adaptive and personalized training to help students with more deficits.

In the two studies in this work, an MR training task has been used that falls within the intrinsic-dynamic category (see Uttal et al., 2013) and that involves manipulation or transformation in an egocentric frame of reference. However, the field of spatial skills could imply the use of very different contexts, such as extrinsic-dynamic ones, and even of an allocentric type, where the frame of reference regarding the stimulus that is rotated is external. This type of spatial scenario is frequently used by drone pilots or air traffic controllers. In this sense, it would be interesting to assess to what extent a training with this type of mental transformation tasks can influence the acquisition of strategies to optimally carry out problems related to STEM domains, where to reach a solution the use of this type of mental representations could be needed.

NOTES

Funding: This work has been partly funded by the project RTI2018-098523-B-I00 " Aprendizaje de habilidades visoespaciales para favorecer la igualdad de oportunidades desde las perspectivas educativas, evolutivas y de género - Learning visuospatial skills to promote equal opportunities from educational, evolutionary and gender perspectives" of the Ministry of Science, Innovation and Universities.

Acknowledgments: The authors wish to thank the C.E.I.P “Escuelas Aguirre” and C.E.I.P “Leopoldo Alas” of Madrid and the CEU-San Pablo Montepríncipe School, for making the sample of participants and the facilities available to carry out the tasks. Also, to Patricia Gimeno (C.E.I.P “Leopoldo Alas”), for opening doors to us unconditionally and for her help with data collection.

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