UDC Subject Classification: 159.95

Academic program and mental rotation performance: Evidence for a developmental effect on individual differences in early adulthood

David Moreau[1-2], Annie Mansy-Dannay[1], Jérôme Clerc[1], Alain Guerrien[1]
[1] University of Lille, France
[2] Dillard University, USA

Abstract
Individual differences in mental rotation are well-documented but poorly understood. In fact, how they evolve across lifespan still remains to be specified. To that purpose, we assessed mental rotation ability in Bachelor of Sciences and Bachelor of Arts American students, during their freshman year. They took the Mental Rotation Test twice, at the beginning and the end of the academic year. Results show significant effects of Academic Program (BS>BA) and gender (males>females) in both sessions, as expected from previous research. However, the Academic Program effect increased significantly from one session to another, with exposure to program-specific learning contents, whereas gender differences remained stable. These findings highlight the developmental effect on mental rotation in a single study, providing further evidence for the plasticity of spatial abilities in early adulthood and the need to reflect on the learning materials used in higher education institutions.

***Keywords**: spatial cognition, mental rotation, academic programs, gender differences, developmental effect.*

People differ in the way they apprehend and represent their spatial environment. Moving themselves and objects through their surroundings, or simply imagining those changes of settings, are different actions that require some form of spatial coding. The efficiency of this coding for a given action influences directly its outcomes. Thus, due to existing discrepancies in spatial coding (among other factors), reasoning on spatial problems yields individual differences in speed and accuracy. These differences can be assessed and measured using adequate tests, in order to anticipate potential weaknesses or strengths among individuals, leading to develop abilities or skills in different areas.

In an attempt to broadly understand individual differences in spatial cognition, a substantial body of literature has shown significant and consistent gender differences on different spatial tasks, such as three-dimensional mental rotation tests. One of them, the Mental Rotation Test (MRT, Vandenberg & Kuse, 1978), has been used extensively in research designs and consistently yielded large gender differences, underlined by extensive meta-analysis studies by Linn and Petersen (1985) and Voyer, Voyer and Bryden (1995). These studies reported better MRT performance for males. This test involves mental manipulation of three-dimensional figures, in order to compare targets and possibly-matching figures. Mental rotation is currently seen as an essential ability in cognition (Johnson & Bouchard, 2005), because of its involvement in many professional areas, as well as in plenty of daily routine tasks, which legitimates the need to further understand the causes underlying interindividual differences in such tasks.

Many explanations have been offered for gender differences in mental rotation tasks. Traditionally, causes have been divided into two categories, biological and experiential. Studies focusing on biological explanations have emphasized differences in cerebral lateralization (McGlone, 1980), as well as maturation and hormones rates (Sanders & Soares, 1986; Imperato-McGinley, Pichardo, Gautier, Voyer, & Bryden, 1991). On the other hand, research concerning experiential factors has underlined the importance of stereotype threat (Shih, Pittinsky, & Ambady, 1999), gender belief (Moè, 2009), role identification (Signorella & Jamison, 1986), and socialization effects (Baenninger & Newcombe, 1989). However, most current theories agree for a combination of both (Halpern & Collaer, 2005).

A growing amount of literature also suggests that some other factors, task-specific, contribute in yielding gender differences. Indeed, research has emphasized the role of cognitive strategies to explain them. According to some studies, males tend to use holistic strategies (rotating the whole figure); whereas females prefer analytic strategy, most often based on verbal cues (Jordan, Wuestenberg, Heinze, Peters, & Jaencke, 2002; Pezaris & Casey, 1991; Peters et al., 1995; Geiser, Lehmann, & Eid, 2006). The former strategy would be more efficient regarding both time and accuracy (Geiser et al., 2006), thus leading males to better overall performance. Besides, males and females could differ in their response strategies, females being more reluctant to guess (Kerkman, Wise, & Harwood, 2000; Peters, 2005; Voyer & Saunders, 2004; Hirnstein, Bayer, & Hausman, 2008). However, this assumption has failed to be confirmed by several studies (Delgado & Prieto, 1996; Masters, 1998).

Although gender differences have been predominantly studied, they are by no means explaining most of the individual variance in mental rotation scores. In fact, they were shown to explain only a limited part of the variance in most studies (see for reviews Linn & Petersen, 1985; and Voyer, Voyer, & Bryden, 1995). Thereby, in an attempt to identify more precisely what underlies individual differences in mental rotation, many studies have also shown a relationship between professional activities, such as surgeon, pilot, dentist, engineer (see Halpern & Collaer, 2005, for a review), and mental rotation ability, or between mathematical and spatial abilities (Geary, 1999). In order to understand the origin of these differences, some experimenters have also assessed the relationship between academic program and mental rotation performance. Indeed, Casey and Brabeck (1989, 1990), as well as many other authors (Lehmann, Jüling, & Knopf, 2002; Lehman & Jüling, 2002; Peters et al., 1995), found a strong tie between academic program and mental rotation performance, mainly dissociating sciences and engineering on one hand, and arts, humanities and social sciences on the other, with the latter showing poorer overall performance.

There is, however, little knowledge about why there are such differences between academic programs (Peters, Lehmann, Takahira, Takeuchi, & Jordan, 2006), and whether students engage in different academic programs depending on their spatial abilities (Casey et al., 1995), or develop these abilities through studying different materials. In fact, it seems likely that both explanations coexist and participate in yielding such differences.

Our previous work has shown a significant effect of sport practice on performance in mental rotation tasks (Moreau, Mansy-Dannay, Clerc, & Guerrien, under review), underlining the plasticity of spatial cognitive processes. Thus, experience and non-specific training (i.e. sport training, not directly related to the task) led to an improvement in performance on a mental rotation task. In the present study, and following our previous finding, we expected individual differences to be shaped drastically by learning contents and materials. In order to test this hypothesis in the academic field, we drew a sample of undergraduate students in their freshman year, from Bachelor of Science (BS) and Bachelor of Arts (BA) programs. They took the MRT twice, at the beginning and at the end of the academic year. From past research on differences in academic programs, we expect to find better performance for BSs than BAs. However, this finding alone would not be of much interest, since it would not provide any new insight. Nevertheless, observing at what stage (first or second trial, that is, before or after being exposed to program-specific contents) differences emerge will provide greater heuristic impact. In fact, to confirm our hypothesis, we should find greater differences between BSs and BAs at the second trial (following one year of their program courses) than at the first trial. This would support the idea of an experiential factor in between-groups differences, and would underline the possibility of training students to develop general spatial skills decisive to their future professional paths.

Method

Participants. 74 BAs (mean age: 18.8) and 59 BSs (mean age: 18.6) Dillard University students volunteered in this study. They all were undergraduates in their freshman year at the time of the experiment, and received no compensation for their participation. They were first tested at the beginning of the academic year, and took the same test again eight months later, at the end of the academic year. During this period, none of the courses the students followed was purposely intended to develop or improve spatial abilities. Besides, no feedback was given to the students after the first session, since this could affect the next one. Also, none of the participants took the MRT prior to the experiment, and none of them was explicitly aware of the present research' hypothesis.

Material and procedure All participants took the MRT-A redrawn from Vandenberg and Kuse (1978), provided by Peters and al. (1995). It includes 24 problems to solve, involving three-dimensional geometric shapes such as Shepard and Metzler stimuli (1971, 1988). For each problem, there are two correct (rotated figures) and two incorrect answers (mirror-imaged figures). The test requires maintaining and manipulating mentally the presented figures with accuracy and speed. As recommended by Peters et al. (1995), we gave three minutes for each part, separated by a 4-minute break.

Participants took the test in a quiet room and all received similar instructions about the task. Therefore, to the best of the experimenter knowledge, conditions were standardized throughout the entire experiment.

We used the same procedure as Peters et al. (1995) for scoring, giving one point only if both answers were correct, for each item. Thus, scores could range from 0 to 24.

Results

We present in this section MRT results for the first and the second sessions (at the beginning and at the end of the academic year, respectively).

Pre-academic session. According to the literature previously detailed in this paper, we expected better performance for BSs and for males in this session. Descriptive statistics are shown in Table 1. Indeed, BS students performed better than BAs regardless of gender and males performed better than females regardless of academic program. We observed a significant main effect for Academic Program (η^2 = .16), and for Gender (η^2 = .32). Also, distribution and variance homogeneity for each group were acceptable, with Kolmogorov-Smirnov and Levene's tests both being non significant.

Table 1: Mean MRT-A performance (out of 24), SD, and effect sizes for academic program and gender (pre-academic session).

		Subgroups				
	Sciences			Arts		
	N	Mean	SD	N	Mean	SD
Males	32	14.60	2.33	35	11.60	3.10
Females	27	10.22	2.64	39	7.49	3.33

Overall Academic Program Effect: df1/132, F=25.4, p<.0001, η^2=.16
Overall Gender Effect: df1/132, F=62.4, p<.0001, η^2=.32

When combining the data in an ANOVA for the between subjects variables Academic Program [BS/BA] x Gender, we observed a significant effect of Academic Program (F=31.5, p<.0001, η^2=.20) and a significant effect of Gender (F=69.1, p<.0001, η^2=.35). However, the interaction Academic Program x Gender was not significant (p=.8). These results show that BSs performed better than BAs and males better than females, in this first session.

These results highlight the fact that Sciences students revealed greater mental rotation ability than Arts students, even before they start following specific courses in their respective curriculum. But does this difference increase with exposure to different materials? Can mental rotation ability be trained and developed into adulthood?

Post-academic session. After a year following program requirements, the same students took the MRT-A for the second time. As observed previously, males performed better than females regardless of academic program, and BS students performed better than BAs. Descriptive statistics for each subgroup are shown in Table 2, including Academic program and Gender effects, as well as the corresponding effect sizes (all significant, with η^2 = .43 and η^2 = .49, respectively). Furthermore, as one could expect due to the particular sensitivity of the task, the whole sample improved. Students gained on average .92 point on the overall score. BSs males gained 1.56, BSs females 1.45, whereas BAs males gained .60 and BAs females .30 on their MRT average scores. Besides, SD was reduced in each subgroup.

Table 2: Mean MRT-A performance (out of 24), SD, and effect sizes for academic program and gender (post-academic session).

		Subgroups				
	Sciences			Arts		
	N	Mean	SD	N	Mean	SD
Males	32	16.16	1.71	35	12.20	2.40
Females	27	11.67	2.40	39	7.79	2.48

Overall Academic Program Effect: df1/132, F=58.0, p<.0001, η^2=.31
Overall Gender Effect: df1/132, F=82.5, p<.0001, η^2=.39

An ANOVA on these data revealed that both Academic Program and Gender variables showed a significant effect on MRT performance (respectively F=96.3, p<.0001, η^2=.43; and F=124.3, p<.0001, η^2=.49). However, the interaction Academic Program x Gender did not show a significant effect. These results mean that, overall, BSs and males performed better than BAs and females in the MRT.

When combining pre-academic and post-academic measures for the same students in a repeated measures ANOVA, we observed a significant effect of the Session [Pre-academic/Post-academic] on MRT performance (F=52.5, p<.0001, η^2=.29). The interaction Session x Academic Program was significant (F=15.1, p<.0001, η^2=.10), but the interactions Session x Gender (F=.57, p=.45, η^2=.004), and Session x Academic Program x Gender (F=.10, p=.75, η^2<.0001) were not. This means that BS students' improvements in performance were greater than BAs, whereas males and females progression were equivalent (see figure 1).

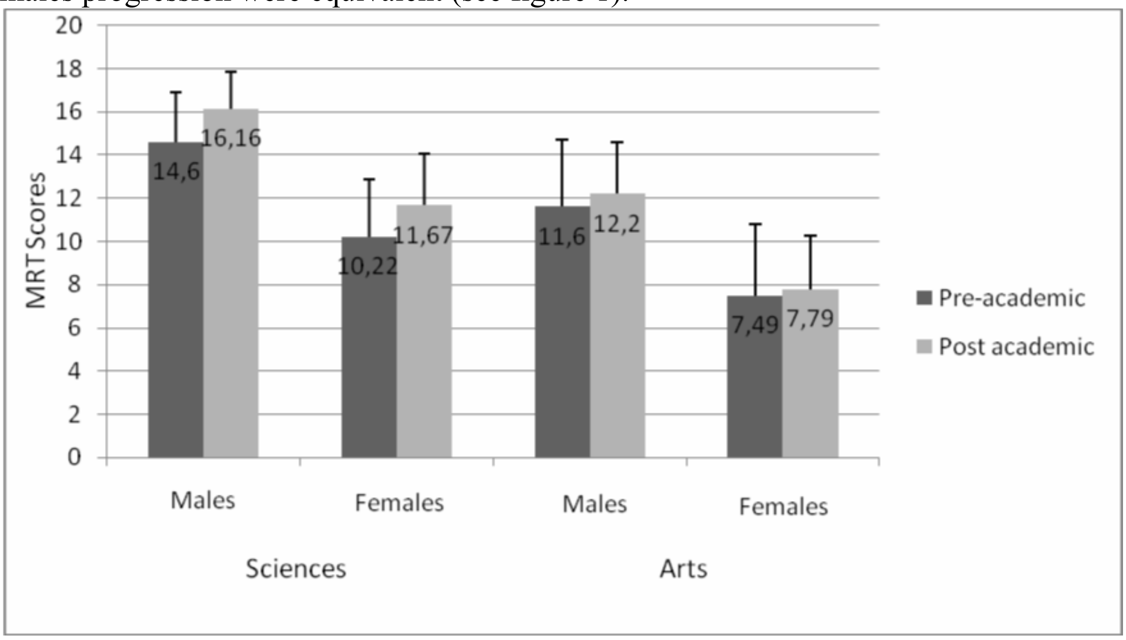

Figure 1: BSs and BAs MRT results in the pre-academic and the post-academic sessions (mean scores and standard deviations).

Discussion

BS students outscored BAs on the MRT in both sessions. This main finding is in line with prior research on the relationship between academic program and MRT performance, and confirms our initial hypothesis. Means, SDs and effect sizes seem to be consistent with previous work by Peters et al. (2006), and we also observed gender differences that confirm a large body of evidence in the field.

However, our central result on Academic Programs can lead to draw two opposite, yet non-exclusive, assumptions:

- Individuals with higher spatial abilities are attracted to activities they excel in, such as those involving spatial skills, and thus are more likely to choose BS programs;
- BS program courses favor the use of spatial abilities through specific content, thus leading students to develop and improve them.

A comprehensive interpretation of the available body of research led most researchers to agree for a combination of both factors (Quaiser-Pohl & Lehmann, 2002; Casey, Nuttall, & Pezaris, 1999). Along with this line of thought, our results show clearly the effects and interactions of pre-existing and experiential differences in a single study. We will detail below each significant result that has been found in the previous section.

In the pre-academic session, we underlined the fact that BSs performed better than BAs, and that males outperformed females, both academic program and gender effects being significant. The results of this first session provided further evidence for correlation between academic program and MRT performance, confirming the existing literature on that matter (Casey & Brabeck1989, 1990; Peters et al., 1995; Lehmann, Jüling, & Knopf, 2002; Lehman & Jüling, 2002). These pretest data were also necessary to evaluate objectively the academic program effect. Thus, the fact that BSs performed better than BAs, even though they were not exposed to radically different materials at school prior to the first session (at least not distinctly), might indicate that BS students are attracted to Sciences because they are at ease with mental transformations of objects, among else. However, a question that is not directly answered by the studies previously mentioned is whether or not mental rotation ability evolves differently from one academic program to another, and thus whether it is improvable with specific contents. This can be a determining factor when considering how spatial abilities in general, and specifically mental rotation, have proved to be decisive in many professional occupations (see Halpern & Collaer, 2005, for a review). Data gathered from the post-academic session shed some new light on that particular issue.

In the post-academic session, we expected an improvement in average scores, since the MRT has shown to be highly sensible to prior expositions (Peters et al., 1995). However, all samples could have improved rather similarly. This was not the case. BSs scores showed greater increase than BAs scores, regardless of gender. Although this could also mean that students with higher spatial abilities tend to develop them more easily, it is more likely to assume that the content they have been exposed to, in the classroom and outside (in their particular fields of interest), have actively participated in the development of their cognitive abilities, such as spatial abilities in the particular case of this study. Besides, it seems like training (indirect training, in this case, since students did not train on the MRT itself) tend to reduce interindividual variances (SDs decrease). A possible explanation is that it might be quite difficult for excellent performers to improve even slightly their performance, whereas even very little progression in lower performers' abilities on this kind of task can produce large changes in overall scores.

However, one should be cautious when interpreting this set of data, especially concerning the identification of the specific variables involved. It should be noted that the increase in scores between the two testing sessions cannot be accounted for by academic exposure only. In fact, students' predispositions toward specific contents and materials favor, consciously or unconsciously, further attractiveness of similar tasks or situations. Thus, different influencing factors can be difficult to isolate, because they can influence and be influenced by mental rotation performance. We do not argue in support of a dichotomist view of mental rotation ability between biological and experiential (or environmental) variables. Rather, the intended purpose of this study is too precise the complexity of the interaction between different factors influencing individual differences, hence leading to put individual heterogeneity into perspective. Indeed, the truly interesting twist of the present study is that it goes against the determinist point of view sometimes surrounding individual differences in spatial cognition. Science students have greater mental rotation ability than Art students (and males show better performance than females), but this can be significantly reduced and overcome if specific material emphasize on that particular facet. Within academics, our results support specific educational actions, such as providing students with opportunities to develop their mental rotation ability, and more generally their spatial ability, through reasoning tasks implying such features.

To conclude, higher spatial abilities in Science programs students seem to be a consequence of both the attractiveness of these programs for higher spatial ability students, but also a consequence of the impact of these programs' contents on students' development. Our findings show that complex and crucial abilities such as spatial ability can still be dramatically developed and improved into early adulthood, in line with recent findings in neuropsychology and neuroscience on human brain's plasticity. Further research will be needed to determine more precisely what kind of material and content shape spatial ability in higher education students, in order to optimize their learning processes and cognitive abilities, and thus match their professional ambitions with the upcoming world.

Acknowledgments

This research was conducted while the first author was supported by a Fulbright fellowship.

Tables: 2
Figure: 1

References

1. Baenninger, M., & Newcombe, N. (1989). The role of experience in spatial test performance: A meta-analysis. Sex Roles, 20, 327–344.
2. Casey, M. B. & Brabeck, M. M. (1989). Exceptions to the male advantage on a spatial task: Family handedness and college major as factors identifying women who excel. *Neuropsychologia, 27*, 689-696.
3. Casey, M. B. & Brabeck, M. M. (1990). Women who excel on a spatial task: Proposed genetic and environmental factors. *Brain and Cognition, 12*, 73-84.
4. Casey M. B., Nuttall, R. L., & Pezaris, E. (1999). Evidence in support of a model that predicts how biological and environmental factors interact to influence spatial skills. *Developmental Psycholology, 35*, 1237-1247.
5. Casey M. B., Nuttall, R. L., Pezaris, E. & Benbow, C. (1995). The influence of spatial ability on gender differences in math college entrance test scores across diverse samples. *Developmental Psychology, 31*, 679-705.
6. Delgado, A. R., & Prieto, G. (1996). Sex differences in visuospatial ability: Do performance factors play such an important role? *Memory & Cognition, 24*, 504–510.
7. Geary, D. C. (1999). Sex differences in mathematical abilities: Commentary on the math-fact retrieval hypothesis. *Contemporary Educational Psychology, 24*, 267-274.
8. Geiser, C., Lehmann, W., & Eid, M. (2006). Separating "rotators" from "nonrotators" in the Mental Rotation Test: A multigroup latent class analysis, *Multivariate Behavioral Research, 41*, 261-293.
9. Halpern, D. F. & Collaer, M. L. (2005). Sex differences in Visuospatial Abilities: More than Meets the Eye. In Shah, P. & Miyake, A. *The Cambridge Handbook of Visuospatial Thinking* (pp. 170-212). Cambridge University Press, New York.

10. Hirnstein, M., Bayer, U., & Hausmann, M. (2009). Sex-specific response strategies in mental rotation. *Learning and Individual differences, 19*, 225-228.
11. Johnson, W., & Bouchard Jr., T. J. (2005). The structure of human intelligence: It is verbal, perceptual, and image rotation (VPR), not fluid and crystallized. *Intelligence, 33,* 393−416.
12. Jordan, K., Wuestenberg, T., Heinze, H. J., Peters, M., & Jaencke, L. (2002). Women and men exhibit different cortical activation patterns during mental rotation tasks, *Neuropsychologia, 40*, 2397-2408.
13. Imperato-McGinley, J., Pichardo, M., Gautier, T., Voyer, D., & Bryden, M.P. (1991). Cognitive abilities in androgen insensitive subjects – Comparison with control males and females from the same kindred. *Clinical Endocrinology, 34*, 341–347.
14. Kerkman, D. D.,Wise, J. C.,&Harwood, E. A. (2000). Impossible “mental rotation” problems. A mismeasure of women's spatial abilities. *Learning and Individual Differences, 12*, 253–269.
15. Lehmann, W. & Jüling, I. (2002). Raumvorstellungsfähigkeit und mathematische Fähigkeiten: Unabhängige Konstrukte oder zwei Seiten einer Medaille? *Psychologie in Erziehung und Unterricht, 49,* 31-43.
16. Lehmann, W., Jüling, I., & Knopf, H. (2002). Allgemeine und domänenspezifische kognitive Leistungen: Eine vergleichende Untersuchung in mathematisch und sprachlich orientierten Gymnasien. *Zeitschrift für Pädagogische Psychologie, 16*, 29-41.
17. Linn, M., & Petersen, A. (1985). Emergence and characterization of sex differences in spatial ability: A meta-analysis. *Child Development, 56*(6), 1479-1498.
18. Masters, M. S. (1998). The gender difference on the Mental Rotations test is not due to performance factors. *Memory & Cognition, 26,* 444–448.
19. McGlone, J. (1980). Sex differences in human brain asymmetry: A critical survey. *Behavioral and Brain Sciences, 3*(2), 215–263.
20. Moè, A. (2009). Are males always better than females in mental rotation? Exploring a gender belief explanation. *Learning and Individual differences*, *19*, 21-27.
21. Moreau, D., Mansy-Dannay, A., Clerc, J., Guerrien, A. (under review). Spatial ability and motor performance: Assessing mental rotation processes in elite and novice athletes.
22. Peters, M. (2005). Sex differences and the factor of time in solving Vandenberg and Kuse mental rotation problems. *Brain and Cognition, 57*, 176–184.
23. Peters, M., Laeng, B., Latham, K., Jackson, M., Zaiyouna, R., & Richardson, C. (1995). A redrawn Vandenberg and Kuse Mental Rotations Test: Different versions and factors that affect performance. *Brain and Cognition, 28*, 39-58.
24. Peters, M., Lehmann, W., Takahira, S., Takeuchi, Y., & Jordan, K. (2006). Mental rotation test performance in four cross-cultural samples (N = 3367): Overall sex differences and the role of academic program in performance. *Cortex: A Journal Devoted to the Study of the Nervous System and Behavior*, *42*(7), 1005-1014.
25. Pezaris, E. & Casey, M. B. (1991). Girls who use “masculine” problem-solving strategies on a spatial task: proposed genetic and environmental factors. *Brain and Cognition, 17*, 1-22.
26. Quaiser-Pohl, C. & Lehmann, W. (2002). Girls’ spatial abilities: Charting the contributions of experiences and attitudes in different academic groups. *British Journal of Educational Psychology, 72*: 245-260, 2002.
27. Sanders, B., & Soares, M.P. (1986). Sexual maturation and spatial ability in college students. *Developmental Psychology, 22*, 199–203.
28. Shepard, R.N., & Metzler J. (1971). Mental rotation of three dimensional objects. *Science, 171*, 701-703.
29. Shepard, S., & Metzler, D. (1988). Mental rotation: Effects of dimensionality of objects and type of tasks. *Journal of Experimental Psychology: Human Perception and Performance, 14*, 3–11.
30. Shih, M., Pittinsky, T.L., & Ambady, N. (1999). Stereotype susceptibility: Identity salience and shifts in quantitative performance. *Psychological Science, 10*, 80–83.

31. Signorella, M.L., & Jamison, W. (1986). Masculinity, femininity, androgyny, and cognitive performance: A meta-analysis. *Psychological Bulletin, 100*, 207–228.
32. Stumpf, H. (1993). Performance factors and gender-related differences in spatial ability: Another assessment. *Memory & Cognition, 21*, 828–836.
33. Vandenberg, S.G., & Kuse A.R. (1978). Mental rotations, a group test of three-dimensional spatial visualization. *Perceptual and Motor Skills, 47*, 599-604.
34. Voyer, D., Voyer, S., & Bryden, M.P. (1995). Magnitude of sex differences in spatial abilities: A meta-analysis and consideration of critical variables. *Psychological Bulletin, 117*, 250-270.
35. Voyer, D., & Saunders, K. A. (2004). Gender differences on the mental rotations test: a factor analysis. *Acta Psychologica, 117*, 79–94.

Article received: 2010-10-29