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Individual Differences in the Mental Rotation Skills of Turkish Prospective Teachers

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Abstract

This study investigated the effects of gender, academic performance and preschool education on mental rotation skills among Turkish prospective teachers. A total of 525 undergraduate students (364 female) from a government university located in western Turkey completed the Mental Rotation Test (MRT). A three-way $[2\ (gender) \times 5\ (academic\ performance) \times 2\ (preschool\ education)]$ *between-subjects analysis of variance (ANOVA) revealed that males outperformed females in mental rotation performance* ($d = .86$)*. Significant effects of preschool education and academic performance on MRT scores were also observed. Significant interactions were observed between gender and academic performance and academic performance and preschool education. There was also a significant three-way interaction of gender, academic performance and preschool education. An interaction between gender and preschool education failed to reach significance.*

Keywords: Spatial thinking, Mental rotation skills, Gender difference, Prospective teachers.

Introduction and Theoretical background

Spatial thinking, which is important across several disciplines including engineering and the basic sciences enables an individual to visualize, edit, reorganize and generalize facts and is required in diverse workplace settings, such as mechanical engineering, pilot training, and scientific crime scene investigation. The development of spatial ability from primary school through college has therefore been the focus of several studies. *Spatial ability* was defined by Lohman (1996) as “the ability to generate, retain, retrieve and transform well-structured visual images”(p.112). Alkan and Erdem (2011) stated that “spatial abilities are described as the combination of the skills such as creating mental pictures of objects in the universe, recognizing in different ways and budging these objects as a whole or in pieces individually”(p. 3446). Linn and Petersen (1985) also defined spatial ability as “skill in representing, transforming, generating, and recalling symbolic, nonlinguistic information”(p. 1482). Several components of spatial ability have been defined in the existing literature. Linn and Petersen (1985) divided spatial ability into three categories: *spatial perception, mental rotation* and *spatial visualization.* Mental rotation is the most intimately known among others which has been defined by Shepard and Metzler (1971) as “the ability to imagine how an object would look if rotated away from the plane or depth in which it is actually presented”.

Several studies have explored mental rotation because of its importance in mathematics, especially 2D and 3D geometry (Olkun, 2003; Reuhkala, 2001), and engineering (Duval, 1998; Sorby, 2009) as well as chemistry, physics (Alkan &

Erdem, 2011; Kozhevnikov, Motes, & Hegarty, 2007) and geography education (Montello, Lovelace, Golledge, & Self, 1999). Mental rotation is also important for coordination in sports science (Moreau, Clerc, Mansy-Dannay, & Guerrien, 2012; Pietsch & Jansen, 2012b) as well as map learning (Pazzaglia & Moe, 2013). Mental rotation is necessary for acquiring mathematical knowledge (Hegarty & Kozhevnikov, 1999; N. Newcombe, 2010), academic thinking and academic performance (Moe, 2009; Peters, Chisholm, & Laeng, 1995; Shea, Lubinski, & Benbow, 2001; Turgut & Yılmaz, 2012). For example, Turgut and Yılmaz (2012) found a positive correlation between spatial ability and academic performance among prospective elementary mathematics teachers. Several studies have identified spatial ability as the main factor in a student's performance in the science, technology, engineering and mathematics (STEM) fields (C. A. Cohen & Hegarty, 2012; Maeda & Yoon, 2013; N. S. Newcombe & Stieff, 2012; Uttal & Cohen, 2012; Wai, Lubinski, & Benbow, 2009), and Kerkman, Wise, and Harwood (2000) have emphasized that "spatial skills such as mental rotation are clearly important for a number high-paying professional careers such as dentistry, medicine, architecture, navigation, and others"(p. 254).

The existing literature reports that males perform better on mental rotation tasks than females (Linn & Petersen, 1985; Maeda & Yoon, 2013; Pietsch & Jansen, 2012a; Voyer, Voyer, & Bryden, 1995). Several factors may explain this gender difference in mental rotation performance. A meta-analysis by Maeda and Yoon (2013) identified five factors that contribute to mental rotation performance: *biological*, *strategic*, *affective*, *test administration* and *experiential*. Evidence regarding the biological factor suggests that performance may depend on an individual's *hormonal levels* or on *hemispheric specialization*. For example, Driscoll, Hamilton, Yeo, Brooks, and Sutherland (2005) and Haussmann, Slabbekoorm, Van Goozen, Cohen-Kettenis, and Güntürkün (2000) both observed that *testosterone* had a strong and positive effect on mental rotation performance and *estradiol* had a negative effect. Furthermore, Hahn, Jansen, and Heil (2010) found that the *brain activity* of preschool boys was lateralized toward the right hemisphere during a mental rotation task, whereas girls exhibited bilateral brain activity.

Researchers have identified two distinct strategies for solving a mental rotation task (Geiser, Lehmann, & Eid, 2006; Janssen & Geiser, 2010; Linn & Petersen, 1985; Moe, 2009; Shepard & Metzler, 1971): a *holistic* strategy in which individuals mentally construct and rotate the stimulus as a whole (i.e., Gestalt-like process) and an *analytic* strategy in which individuals manipulate the components of the stimulus part by part. Janssen and Geiser (2010) describe the holistic strategy as a mental transformation and note that the mental rotation is completed quickly (p. 473). In contrast, the analytic strategy focuses on the details of the stimulus and therefore requires more time to complete mental rotation. Studies revealed that the holistic strategy was more commonly preferred in male subjects (Linn & Petersen, 1985; Peters, 2005; Peters, Laeng, et al., 1995), which may explain the persistent male advantage in mental rotation performance.

Recent studies have revealed that the *individual's affective state* may also affect mental rotation performance (Maeda & Yoon, 2013). For example, Moe (2009) investigated the effect of motivation on individual's mental rotation performance. Participants were divided into three groups and provided with different instructions: Group 1 was told that men are better than women at this task. Group 2 was told that women are better than men at this task and Group 3 was a control group that was given instructions that did not refer to gender. The instructions affected the mental rotation performance of the female subjects such that their scores reached the same levels as the scores of the male subjects. A recent study showed that another psychological factor, called the stereotype threat effect, also affected the MRT performance of female subjects (Moe & Pazzaglia, 2006).

The quality of the test administration is important to exclude measurement errors in mental rotation performance(Maeda & Yoon, 2013). Although some studies have found that the time limit for the MRT may offer an advantage to males, the effect of the time limit has been inconsistent across studies. For example, the gender difference in mental rotation performance disappeared when the time limit was removed from the task (Goldstein, Haldane, & Mitchell, 1990). However, Titze, Heil, and Jansen (2008) have disproven this hypothesis, as cited in (Maeda & Yoon, 2013).

Some studies have provided that evidence that engagement in spatial activities, such as dotted paper, isometric drawings, Legos and model building models may develop spatial ability (Ginn & Pickens, 2005; Kurtulus, 2011; Nazareth, Herrera, & Pruden, 2013; N. Newcombe, Bandura, & Taylor, 1983; Olkun, 2003). For example, N. Newcombe et al. (1983) found a significant correlation between spatial visualization ability and individuals who participated in spatial activities. Nazareth et al. (2013) also observed a significant relationship between the sex of the participant and the MRT score that was partially mediated by the number of spatial activities in which the participants had engaged during their youth. Similarly, Sorby (2009) concluded that activities that require hand-eye coordination may improve the development of spatial skills. Uttal et al. (2013) observed that spatial ability can be improved across all age groups. However, İrioğlu and Ertekin (2012) found that middle school students who had received a preschool education outperformed students who had not received a preschool education on a mental rotation task, which suggests the engagement in spatial activities at an early age can influence overall spatial ability. Turgut (2007) observed similar results for spatial visualization performance in middle school students. Researchers therefore suggest that engagement in spatial activities should be provided to enhance mathematical thinking, mathematical reasoning and problem solving performance (Hung, Hwang, Lee, & Su, 2012).

In sum, I hypothesized that gender; academic performance and one year preschool education may significantly affect the mental rotation performance of Turkish prospective teachers. To our knowledge, this study is the first to examine the effect of these variables and their interactions on mental rotation performance among Turkish prospective teachers.

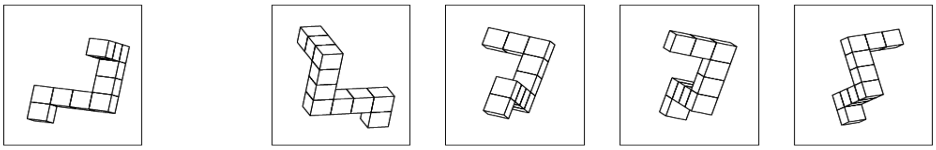
Methods

Participants

The participants in the present study included $N = 525$ sophomore-level undergraduate students from education faculty of a government university in western Turkey. The mean age was 19.4 years old ($SD = .87$) with a range of 18 to 25 years old. The convenience sample included 364 females and 161 males. All of the participants belonged to one of four education departments: computer and instructional education (36 females and 45 males), mathematics education (112 females and 36 males), primary school education (91 females and 31 males) and science and technology education (125 females and 49 males).

Materials

Mental rotation test. A paper-and-pencil mental rotation test, the MRT (version A) by (Peters, Laeng, et al., 1995) was used to assess mental rotation performance. The MRT (version A) was originally developed by Vandenberg and Kuse (1978) and consists of two sets of 12 items. Each item consists of 5 stimuli (see Fig. 1), which include a target that consists of three-dimensional cubes (the left most stimulus in Fig. 1) and four alternatives. Two of the four alternatives match the target when mental rotation is applied. The remaining two alternatives are distractors. The MRT (version A) has a reliability of $.87$ as measured by Cronbach's α, and $.80$ as measured by the split-half reliability in $N = 1695$ subjects (Geiser et al., 2006).



The Target Item The Alternatives

Figure 1. *Sample MRT task*

Procedure

I collected the all data during the spring semester of 2012. Each participant completed a consent form that included a description of the spatial test. Participants provided information about their grade point average (GPA), preschool education and its duration and gender. The MRT was administered in small groups (a maximum of 30 participants). The instructions and scoring method were explained to all participants, and each participant completed three sample items to acclimate to the task. The participants were provided with feedback, about the sample items and further instructed about the time allotted to complete the MRT. The MRT was administered to each participant in a block that consisted of four DIN A-4 sheets with six items per sheet. Participants were allowed 3 min for each set of 12 items, and sets were separated by a 2-min break. Two methods of scoring the MRT have been described in the literature. In the first method, a point is awarded for each correct answer. In the second method, a point is awarded if and only if both correct stimuli are identified, which *discourages guessing* (Peters, 2005). In this study, the second method was preferred and therefore the maximum possible score was 24 points.

Statistical analysis

Mental rotation performance was quantified as the number of correctly solved items (i.e., the number of items for which the participant identified both correct alternatives). The reported GPA by students considered as academic performance. Descriptive statistics (i.e., mean, standard deviation, standard error, and frequency) were calculated with respect to the gender, preschool education and academic performance of the participants. According to normal distribution of the GPA values, it has been divided into five groups. Three between-subjects effects on mental rotation performance were examined: gender (male vs. female), academic performance (GPA interval: $0 - 1.99$, $2 - 2.49$, $2.5 - 2.99$, $3 - 3.49$ and $3.5 - 4$) and preschool education (yes, no and year of the education). Only one-year preschool education considered and a three-way between-subjects analysis of variance (ANOVA) was conducted with MRT scores as the dependent variable. The effect sizes for Cohen's d E. Cohen (1988) were classified as follows: to $.20$ as small, $.50$ as medium and above $.80$ as large. The results were calculated using a default critical value of $.05$. A Bonferroni correction was applied for all post-hoc pairwise comparisons.

Results

There was a significant effect of gender ($F(1{,}505) = 40.33, p < .001, \eta^2 = .063$), academic performance ($F(4{,}505) = 3.19,\ p < .05, \eta^2 = .020$) and preschool education ($F(1{,}505) = 5.14,\ p < .05, \eta^2 = .008$) on the MRT scores. There was a significant interaction between the factors gender and academic performance ($F(4{,}505) = 2.86,\ p < .05, \eta^2 = .017$) and academic performance and preschool education ($F(4{,}505) = 4.72,\ p < .05, \eta^2 = .029$). There was also a significant three-way interaction of gender, academic performance and preschool education ($F(4{,}505) = 2.48, p < .05, \eta^2 = .015$). No significant interaction was found between gender and preschool education ($F(1{,}505) = 1.24, p = .266, \eta^2 = .001$).

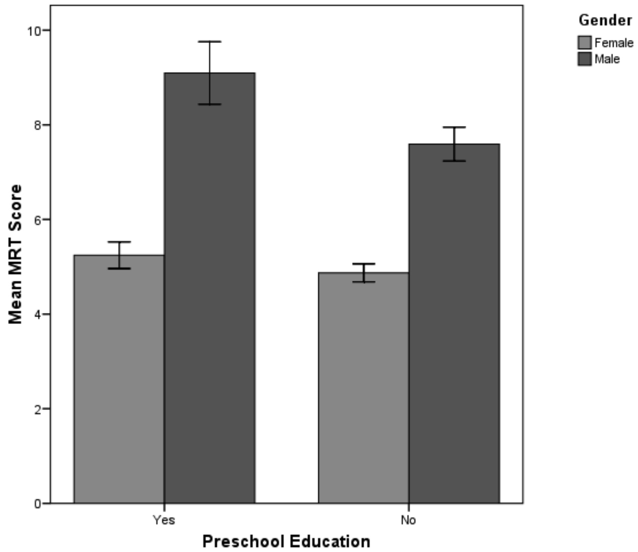


Figure 2. *MRT performance (means and standard errors) as a function of gender and preschool education*

There was a large effect of gender ($d = .86$) on the MRT scores. Figure 2 shows that males ($M = 7.88, SE = .50$) outperformed females ($M = 4.99, SE = .22$) on the MRT. Students with a preschool education ($M = 6.01, SE = .46$) solved more items correctly than students without a preschool education ($M = 5.82, SE = .29$), but the effect size was small ($d = .05$) (see Figure 2). A post-hoc Bonferroni-adjusted pairwise comparison revealed that students with $3.5 - 4$ GPA ($M = 6.52, SE = 1.07$) solved more items correctly than students with either a $3 - 3.49$ ($M = 5.44, SE = .55, d = .32$) or $2.5 - 2.99$ ($M = 5.35, SE = .37, d = .38$) GPA (see Figure 3).

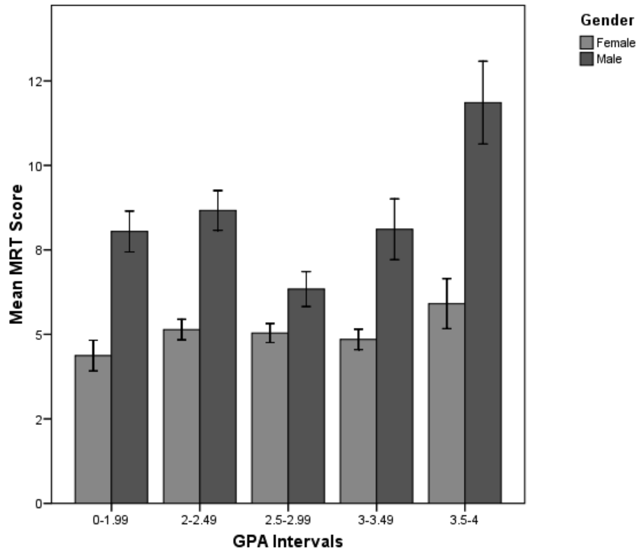


Figure 3. *MRT performance (means and standard errors) as a function of gender and academic performance*

A significant interaction between the factors gender and academic performance was due to gender differences in each GPA group (i.e., males significantly outperformed females in each GPA group, see Figure 3). The gender differences was significant for the following GPA intervals: $0 - 1.99$, ($F(1{,}515) = 26.78, p < .001, \eta^2 = .052$) (males $M = 8.04, SE = .52$, females $M = 4.37, SE = .49$, $d = 1.04$), $2 - 2.49$ ($F(1{,}515) = 38.20,\ p < .001, \eta^2 = .074$) (males $M = 8.66, SE = .70$, females $M = 5.14, SE = .36$, $d = 1.01$), $2.5 - 2.99$ ($F(1{,}515) = 4.73,\ p < .05, \eta^2 = .009$) (males $M = 6.34, SE = .67$, females $M = 5.03, SE = .31$, $d = .41$), $3 - 3.49$ ($F(1{,}515) = 14.13,\ p < .001, \eta^2 = .027$) (males $M = 8.11, SE = 1.03$, females $M = 4.85, SE = .39$, $d = 1.12$), and $3.5 - 4$ ($F(1{,}515) = 6.18,\ p < .05, \eta^2 = .012$) (males $M = 11, SE = 2.01$, females $M = 5.90, SE = .78$, $d = 2.48$). All the Cohen's d values except for the $2.5 - 2.99$ interval indicate large gender effects. There was also a significant main effect of GPA in males ($F(4{,}515) = 3.65, p < .05, \eta^2 = .028$). Males with GPAs in the range of $0 - 1.99$, $2 - 2.49$ and $3.5 - 4$ solved more items correctly than males with $2.5 - 2.99$ GPA. There was no significant main effect of GPA among females ($F(4{,}515) = .88,\ p = .476, \eta^2 = .006$).

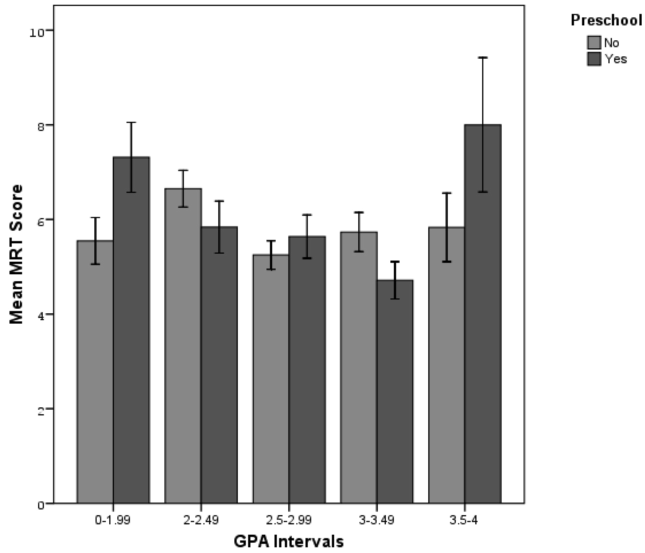


Figure 4. *MRT performance (means and standard errors) as a function of academic performance and preschool education*

There was a significant preschool effect among participants with a $0 - 1.99$ GPA ($F(1{,}515) = 5.17, p < .05, \eta^2 = .001$). Figure 4 shows that participants with a preschool education ($M = 7.31, SE = .60$) outperformed students without a preschool education ($M = 5.54, SE = .49$) with an effect size of $d = .45$ for this GPA interval. There was no significant effect of preschool education among the remaining GPA intervals. However, there was a significant effect of GPA among students with a preschool education ($F(4{,}515) = 2.95,\ p < .05, \eta^2 = .022$). Students with a preschool education and a $0 - 1.99$ GPA solved more items than both students with a preschool education and a $2.5 - 2.99$ GPA ($M = 5.63, SE = .52$) with $d = .45$ and students with a preschool education and a $3 - 3.49$ GPA ($M = 4.71, SE = .67$) with $d = .74$. Students with a preschool education a GPA of $3.5 - 4$ ($M = 8.28, SE = 1.34$) also outperformed students with a preschool education and a GPA of $3 - 3.49$ ($d = 1.21$). There was no a significant effect of GPA among students without a preschool education ($F(4{,}515) = 2.33, p = .05, \eta^2 = .018$).

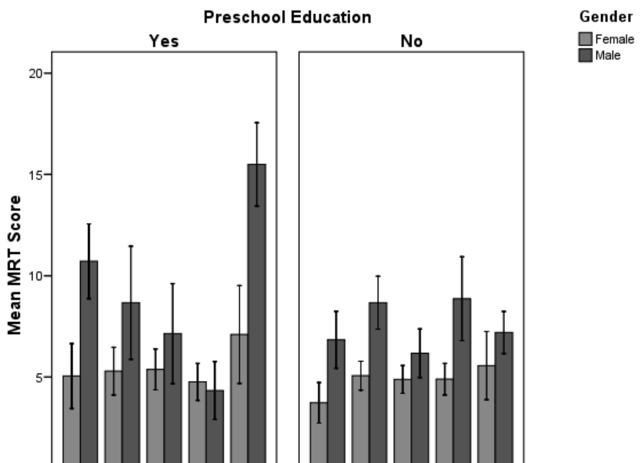


Figure 5. *MRT performance (means and standard errors) as a function of gender, academic performance and preschool education*

Figure 5 demonstrates the three-way interaction of gender, academic performance and preschool education on MRT scores. There was a significant effect of male gender in the $0 - 1.99$ GPA group for both participants with a preschool education ($F(1{,}505) = 25.17,\ p < .001, \eta^2 = .049$) (males $M = 10.71, SE = 1.33$, females $M = 5.04, SE = .71$, $d = 2.47$) and participants without a preschool education ($F(1{,}505) = 11.62,\ p < .05, \eta^2 = .023$) (males $M = 6.83, SE = .58$, females $M = 3.72, SE = .69$, $d = .96$). A gender effect was also observed among students with a $2 - 2.49$ GPA for participants with a preschool education ($F(1{,}505) = 5.34, p < .05, \eta^2 = .010$) (males $M = 8.66, SE = 1.33$, females $M = 5.29, SE = .58, d = 1.10$) and participants without a preschool education ($F(1{,}505) = 32.50$, $p < .001, \eta^2 = .064$) (males $M = 8.66, SE = .47$, females $M = 4.50, SE = .41$, $d = .99$). Among males with a preschool education ($F(4{,}504) = 4.54, p < .05, \eta^2 = .036$), males with a $3.5 - 4$ GPA ($M = 16.78, SE = .86$) outperformed males with a $2 - 2.49$ GPA ($d = 3.70$), $2.5 - 2.99$ ($M = 7.14, SE = 1.23$, $d = 4.10$) and $3 - 3.49$ ($M = 4.33, SE = 1.89, d = 4.63$) GPA. An academic performance effect was also observed among males without a preschool education ($F(4{,}504) = 3.86, p < .05, \eta^2 = .030$). In this group, males with a $3 - 3.49$ GPA ($M = 8.86, SE = .84$) solved more items correctly than males with a $2.5 - 2.99$ ($M = 6.17, SE = 1.23, d = .77$) or $0 - 1.99$ ($M = 6.83, SE = .58, d = .54$) GPA. A preschool effect was also observed in males with a $0 - 1.99$ GPA ($F(1{,}505) = 13.51, p < .001, \eta^2 = .026$). Males with a preschool education outperformed males without a preschool education in this GPA interval ($d = 1.15$).

Discussion

The present study showed significant effects of gender, academic performance and preschool education on the mental rotation performance of Turkish university students. The average MRT scores of these students were lower than those of their counterparts from other countries (Bors & Vigneau, 2011; Cooke-Simpson & Voyer, 2007; Janssen & Geiser, 2010; Peters, 2005; Pietsch & Jansen, 2012a). The literature describes a positive relationship between spatial ability and mathematics achievement (Battista, 1990; Kayhan, 2005; Turgut, 2007). Therefore, low MRT performance among the Turkish university students in the present study may be due to the limited spatial activities that were offered in the middle school mathematics curriculum prior to 2005. Several spatial activities were implemented within the new mathematics curriculum that was adopted in 2005, which renewed the view of a constructivist perspective in mathematics education (Turgut & Uygan, 2014). Spatial ability has also been emphasized in the national central mathematics questions (Uygan & Turgut, 2012). Therefore, we hypothesize that a parallel study conducted in undergraduate students who have been exposed to the new curriculum would show that these students have superior mental rotation ability compared with the students in the present study. In addition, *future work* is needed to review the implementation of activities that develop spatial ability among curriculums from other countries whose students achieve high mental rotation performance. This future work may reveal important evidence about the development of mental rotation ability in students.

Gender differences may also be the result of sociocultural differences (Moe, 2009). For example, Nazareth et al. (2013) concluded that spatial experience (sex-typed masculine, sex-typed feminine and neutral spatial activities) is partially associated with MRT scores. Turkish versions of *spatial activity surveys* (Cherney &

Voyer, 2010; N. Newcombe et al., 1983) may be developed and used to examine the low mental rotation performance among Turkish individuals.

The present study in a population of sophomore-level Turkish university students has replicated the gender differences in mental rotation performance that has been observed in other studies. The effect size of gender in the present study was in the range reported by Voyer et al. (1995). Gender differences in mental rotation have important implications because a reduction in this difference may result in more success among females in the STEM fields. The gender difference among Turkish university students may be related to their MRT solution strategies (Janssen & Geiser, 2010; Voyer & Doyle, 2010). The reasons for a gender difference in strategy are important to address to reduce the gender effect size. For example, Quaiser-Pohl, Geiser, and Lehmann (2006) reported that a computer game preference was associated with MRT scores in males but not females. This study observed that girls prefer logic and skill-training games, whereas boys prefer action and simulation computer games. Therefore, the gender difference in mental rotation performance may be related computer game preference in addition to spatial experience, hormonal status and brain specialization. These types of analyses will further explain the gender difference as well as poor mental rotation performance.

The results of the present study also indicated an effect of preschool education and academic performance on mental rotation performance. Students with a preschool education solved more items correctly than students without a preschool education. Although the effect size of one-year preschool education was small ($d = .05$), this result confirms an influence of preschool education on MRT scores (İrioğlu & Ertekin, 2012; Turgut, 2007). A medium effect size of academic performance was observed among the higher GPA groups, which confirms the hypothesis that mental rotation performance is related to academic achievement (Peters, Chisholm, et al., 1995; Uttal & Cohen, 2012).

One limitation of this study is that the study was underpowered to compare mental rotation performance across departments. All the students in the current study were enrolled in education departments. Pietsch and Jansen (2012a) found a better mental rotation performance in music and sports students compared with students in an education discipline. Therefore a larger sample across the whole university, such as the study conducted by Hegarty, Crookes, Dara-Abrams, and Shipley (2010) may reveal addition differences in mental rotation performances among students.

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