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Summary
Spatial Representation: The Effect of Spatial Thinking on Mental Rotation Performance

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Spatial processing, by definition, extends from very trivial tasks such as moving without bumping into furniture to reading a map or driving. Knowing the internal representations of a given structure or an environment is also within the realm of spatial cognition. In order to carry out these tasks we continuously process spatial information and create spatial mental models (Taylor & Tvesky, 1996) upon which we rely on for later use. Factors such as our preferences, representations, and strategies were suggested to affect the way we think about space. Understanding the individual differences, especially frequently reported sex difference, is important for spatial processing. The current study, based on the previous work (Bilge & Taylor, 2017), investigated the underlying reasons for possible performance difference in spatial tasks by holding the gender variable constant. By measuring spatial ability and assessing spatial thinking style, the study aimed to show the variance even within a same-sex group suggesting spatial representation to be an alternative factor to account for the difference in MR performance.

One way to investigate how people process spatial information is people's spatial thinking style. From very early on we learn to think about space in certain ways: how we prefer to receive spatial information and how we mentally represent this knowledge, a term we coined as *habitual spatial thinking* (Bilge & Taylor, 2017). Information could be processed at a more global level via survey perspective or at more local level via route or landmark perspective. Pazzaglia and De Beni (2001) designed a questionnaire to categorize people as having survey-, and landmark-centered representations. The resultant mental representations are also related to performance on spatial tasks. People with a tendency to create survey-representations scored better on a mental rotation test compared to individuals who habitually took a landmark-centered approach (Pazzaglia & De Beni, 2001; 2006). Thus, one's spatial representation (survey or landmark) has major appears to have an impact on spatial processing.

Another way to investigate spatial processing is through tasks that measure spatial skills. A small-scale task such as Mental Rotation (MR) (Shepard & Metzler, 1971; Vandenberg & Kuse, 1978). MR is one of the most commonly used tests to assess spatial ability. In classic MR experiments (Shepard and Metzler, 1971), participants decide whether two figures are the same or mirror images of one another. To solve this problem, they need to rotate one of the figures to match with the other one (Gardony, Taylor, & Brunye, 2014). The pair could be rotated versions of one another, which would need a "same" judgment, or one of the figures could be flipped creating mirror reflections of the pair, which would require a "different" judgment. The most common finding is the decreased rotation rate and accuracy ratio with the increase in angular disparity between the figures. The other common finding is men outperforming women in rotation (Linn & Petersen, 1985; Voyer, Voyer, & Bryden, 1995). In reality this male advantage may be more complex. Some studies have found no sex difference (Butler et al., 2006; Heil & Jansen-Osmann 2008; Jordan et al., 2002) and in other studies women were faster. Variability in MR sex differences suggests that other factors may contribute to MR performance.

Sex difference was suggested to stem from the way people solve these problems; applying different strategies (Kail, Carter, & Pellegrino, 1979). Two MR strategies have been proposed basing on the pattern of rotation performance: *holistic* and *piecemeal*. While mentally rotating 3D figures, men seem to rotate the figures as a whole, applying a holistic strategy, and women were suggested to use a piecemeal strategy where they divide the figure into its pieces, rotate each piece in their minds, then put the resultant pieces back together. This, of course, is a more tedious process and is suggested to be the reason for reported sex difference. However, to en-

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gage the use of piecemeal strategy, cut figures were used in this research following earlier work (Bilge & Taylor, 2017; Boone & Hegarty, 2017). This is a novel approach to examine the strategy used in MR task.

Current research

Cognitive strategies used in MR problems were suggested to account for the variance in performance. *Holistic* strategy users rotate 3-dimensional figures as a whole whereas *piecemeal* strategy users rotate in pieces. However, there is not a direct link between sex and strategies, as suggested. Moreover, great variability in MR performance points to other possible contributing factors. Previous work found spatial thinking style (e.g., mental representation) to be one of those factors (Bilge & Taylor, 2017). The current study, investigated the effect of different mental representations on MR performance while keeping sex constant. If within an all-woman sample, different mental representations and strategies are found to affect MR performance it would suggest a link between spatial thinking style and MR.

Method

Participants

Sixty-one women undergraduates (M = 21.2, SD = 2.6) from Istanbul Sehir University (28 survey, 33 landmark representations) were recruited in this experiment.

Materials

MR Stimuli were 3-D block figures. They were presented in pairs that were defined by two factors, *figure presentation* (whole, cut) and *angular difference* (0-, 30-, 60-, 90-, 120-, 150-, and 180- degrees). These 3D block figures comprised the *whole* figures. *Cut* figures were created dividing the *whole* figures into two parts.

Mental Representation Questionnaire (Pazzaglia & De Beni, 2001) examined spatial processing habits by asking 17 questions on a 5-Likert scale. The statements asked participants to rate their answers from 1 to 5, 1 indicating *"not agree at all"* and 5 *"agree very much"*. Cumulative scores allowed participants to be categorized as creating more survey-representations, or landmark-representations when encountering larger scale environmental information.

Santa Barbara Sense of Direction Scale (Hegarty et al., 2002) was used to assess one's sense of direction through self-report. There were 15 statements, which needed to be rated on a 7-Likert-type scale. Participants chose from "1" (totally agree) to "7" (totally disagree) and their total scores were calculated to identify them as having high or low sense of direction.

Procedure

All the participants were presented with a block of whole figures and a block of cut figures, in counterbalanced order. They then completed the questionnaires, through which they were categorized as having survey- or landmark-representations.

Results

A 2 X 7 X 2 repeated-measure ANOVA was conducted, where Rotation Degree (0^0- to 180^0) and Figure Presentation (whole and cut) were within-participant variables and Spatial Representation (survey and landmark) was a between-participant variable. Dependent variables were reaction time (RT) and accuracy rate.

There was a main effect of Rotation Degree for RT data, $F(2.59, 152.59) = 82.8$, $p < .001$, $\eta P2 = .584$. Furthermore, Rotation Degree showed a main effect for accuracy data, $F(3.66, 215.78) = 33.07$, $p < .001$, $\eta P2 = .359$ supporting the Angular Disparity Effect. Participants responded slower and less accurately as the degree of rotation between the figure pairs increased.

There was an interaction between Rotation Degree and Spatial Representation, $F(6, 354) = 3.53$, $p = .021$, $\eta P2 = .057$. With increasing angular disparity between the figures, participants who relied more on survey-representations performed faster while the smaller angular disparities did not show that difference between survey- and landmark users.

An interaction between Rotation Degree and Figure Presentation was also observed, for both RT ($F(5.45, 321.55) = 2.59$, $p = .022$, $\eta P2 = .042$) and accuracy data ($F(5.54, 326.86) = 6.43$, $p < .001$, $\eta P2 = .098$). The pattern for rotation of whole and cut figures flipped with increasing angular disparity. For relatively smaller disparity, cut figures seemed to be rotated more accurately yet this changed with greater disparity.

Discussion

The current research supported and extended the previous literature on MR. Findings supported the literature by showing the angular disparity effect. Participants rotated 3D images in their minds more slowly and less accurately as the angular disparity between the figures increased. The study also extended the literature by introducing strategy-consistent stimuli (*cut* versions to engage piecemeal processing and *whole* figures for using holistic strategy) to an all-women population. If the women showed variance in their performance, then sex would not be the factor to explain the said difference since it was held constant. Therefore, the findings suggested that there could and should be other factors to account for these individual differences such as spatial thinking style.

Another factor that was found to influence MR performance in some form was the way we represent the environment in our minds (spatial representation). When encountered with larger-scale environments, people create spatial mental models (Taylor & Tversky, 1996) and represent space either with a survey or landmark perspective (Easton & Sholl, 1995; Pazzaglia & De Beni, 2001). In the literature, women were also suggested to use a piecemeal strategy with MR and to rely more on landmark representations. However, the current study sample consisted of women who created landmark or survey representations, both. Furthermore, the results of the current study mimicked the literature (Bilge & Taylor, 2017) by showing varying MR performances by participants with survey and landmark representations, observed with the increasing angular disparity. Again, MR performances differed while rotating whole and cut figures, especially over degrees of rotation. The combination of these factors and examining their joint effects is new to the literature. Furthermore, drawing a possible link between how we come to think about larger-scale environments and how we solve smaller-scale MR problems would be influential for future of spatial cognition.