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Mental rotation of emotional and neutral stimuli

The main aim of the study was to create and validate emotional version of mental rotation task (MRT). As all previously conducted experiments utilized neutral material only, such an attempt seemed necessary to confirm the generality of mental rotation effect and its properties. Emotional MRT was constructed using photos of negative facial expressions; a compatible neutral MRT was also created, for detailed comparisons. 2- and 3-dimensional figures (Experiment 1) and hexagrams (Experiment 2 and 3) served as affect-free stimuli. In three experiments, emotional MRT version was proven to be valid, whereas only hexagram-based neutral MRT version yielded the expected results. A number of differences between the two versions emerged, concerning response times, accuracy and difficulty of trials. The neutral/emotional MRT procedure, although needing more research, seems to give stable results, making the study of content-bound imagery possible.

Keywords: *imagination, mental imagery, mental rotation, emotion*

Introduction

According to Cohen and Kubovy (1993), the term „mental rotation" can be understood twofold. Firstly, it describes an act of imagining a shape or object turning around (Corballis & Corballis, 1993). Defined in such manner, the concept refers to a complex cognitive operation of mental form reorientation. Secondly, the term mental rotation also pertains to a task that is assumed to involve manipulations carried out on an internal image (mental rotation task; MRT).

The mental rotation paradigm, introduced by Shepard and Metzler (1971), is widely used to investigate the nature of mental rotation as a process. In their experiment, participants had to judge whether two differently oriented three-dimensional figures are the same in shape or are mirror images of each other. The time needed to make such a judgment was a linearly increasing function of angular disparity between the figures – the bigger the difference, the more time was necessary to complete the task. Cooper and Shepard (1973) obtained the same effect using alphanumeric characters as stimuli. However, mean response time increased with angular disparity increment only to 180^{o} and monotonically decreased when angular difference exceeded 180^{o}. Thus, the relationship between rotation angle and reaction time is in fact curvilinear.

Shepard and his colleagues assumed that such tasks are accomplished by generating mental image of the disoriented shape, which is subsequently normalized (to upright position) and compared with the second figure. Rotation is believed to be carried out in analog and holistic manner in the direction that ensures reaching the final position the fastest. The latter explains reaction times decrement after 180^{o} disparity, which is caused simply by changing the rotation direction. The rate of mental rotation was thought to be constant (about 60^{o}/sec in Shepard & Metzler, 1971).

The mental rotation effect was subsequently replicated in many studies with the use of various stimuli, e.g. polygons (Cooper, 1975), matrix patterns (Bethell-Fox & Shepard, 1988); and real-life objects (McMullen & Jolicoeur, 1992), being now one of the best known and well examined cognitive effects. However, mental rotation as a process was found to be influenced by many variables, associated with the task properties as well as with the task performer's individual characteristics. These factors usually change the shape of mental rotation curve slightly, although, in some cases, they may prevent rotation effect from occurring.

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Task properties that moderate MRE

One important, yet largely ignored, moderating factor associated with the mental rotation task is its general design. The MRT procedure can take one of two main forms. "Handedness recognition task" uses mirror images of stimuli (i.e. isomers; Shepard & Metzler, 1971) in negative response condition, whereas "form identification task" requires differentiation between stimuli of different shapes (i.e. mutants; Folk & Luce, 1987). According to Cohen and Kubovy (1993), only the former guarantees engagement of mental rotation process while the latter encourages non-rotational solving strategies, such as salient features comparison. Moreover, handedness recognition task usually generates longer reaction times. Koriat, Norman and Kimchi (1991) suggested that while performing this task an additional time is required to "flip" the reflected image after it had been normalized. Additionally, the stimuli can be presented to subjects either simultaneously, i.e. both at the same time, or sequentially, i.e. one after another. The classic mental rotation curve is more frequently obtained with the use of simultaneous display (Shepard & Metzler, 1988). The sequential presentation is more demanding – the template (stimulus shown first) must be stored in working memory for the subsequent comparison with the probe (stimulus shown as the second one).

Although MRE has been obtained with the use of various material, the shape of the curve and the rate of mental rotation are not independent of stimuli dimensionality. Using two- and three-dimensional stimuli, Shepard and Metzler (1988) discovered that 2D shapes were rotated at much faster pace than 3D shapes. Bauer and Jolicoeur (1996) confirmed this outcome. They also showed that the slope of mental rotation curve for 3D figures was more steep in comparison to the slope of the curve for 2D objects. This effect was augmented when shapes had to be rotated in depth, not in plane of presentation. These results suggest that reorientation of a three-dimensional stimulus is more difficult and requires more time. However, it does not imply that the mental rotation rate varies itself with the number of shape dimensions. Bethell-Fox and Shepard (1988) suggested that the number of stimulus dimensions affects the coding phase (i.e. the initial generation of an image), but it has no impact on the rate of "pure" rotation process. Reflecting complicated structure of figures in a mental image seems to be more time-consuming. Thus, mental rotation effect may also be moderated by stimulus complexity. Rotation of figures labeled as complex (i.e. irregular, asymmetric, with many sides and various angles) requires more time in comparison to rotation of simpler shapes (Folk & Luce, 1987). However, Cooper (1975) failed to obtain this relationship. She explained the lack of effect by specificity of the used stimuli. When figures facilitate alternative solving strategies, mental rotation curve becomes flat and stimulus complexity has no impact on MRE. Finally, Collins and Kimura (1997) found an interesting interaction between both mentioned above stimuli properties – dimensionality and complexity. Complex two-dimensional shapes can be more difficult to rotate than simple three-dimensional ones.

Training completed prior to the task was found to be the next significant moderator of mental rotation efficiency. Cooper (1975) discovered that reaction times shortened throughout consecutive sessions of mental rotation task. According to Heil et al. (1997), this effect can be explained twofold. Firstly, it is possible that rotation process itself is being trained. Over time, redundant and ineffective subroutines are eliminated and coherence of the whole operation increases, resulting in proficiency. Secondly, prolonged practice with the MRT along with familiarization with both stimuli and possible solutions results in storing all of the task items in memory. Thus, after the practice period, solving the mental rotation task is based solely on retrieving previously remembered answer. In such case, mental rotation does not occur. Heil and his colleagues obtained the results that supported the second of the two above mentioned explanatory hypotheses. Practice provided to the participants significantly decreased reaction times in the main task, but only in trials identical with training phase. Nevertheless, Pavlik and Anderson (2002) observed a transfer from training phase to the main task with new stimuli views, suggesting that training effect can not be based entirely on memorization of correct responses. Also Bethell-Fox and Shepard (1988) pointed out that experience in handling specific stimuli, acquired during training, might result in improved coding and image formation of the stimuli displayed during the main task, thus reducing the overall reaction time.

Finally, time pressure is also an important factor that moderates the course of mental rotation process. In Cohen and Kubovy's (1993) mental rotation experiment, participants who did not provide an answer in a given, rather short time, heard a loud unpleasant sound emitted by the computer. As the result of induced time pressure, mean RT was found to be very short, constant and independent of angular disparity between templates and probes. At the same time, error rate increased significantly. The latter suggests that, in time pressure condition of mental rotation task, the participants rather guess or use other perceptual solving strategy than rotate the objects. Results obtained by Cohen and Kubovy were replicated by Cohen and Blair (1998). Thus, it may be concluded that time pressure prevents rotation from occurring.

Participants' characteristics that moderate MRE

As far as individual characteristics are taken into account, participants' gender seems to be one of the most important moderators of mental rotation efficiency. Women usually perform worse than men in a variety of spatial tasks that require generation, maintenance and manipulation of mental images. In the case of MRT, this difference exceeds one standard deviation, being one of the most profound gender differences discovered with regard to cognitive processes (Collins & Kimura, 1997). It is especially salient in difficult task conditions (e.g. when rotated stimuli are complex). The gender impact on mental rotation efficiency was found to be stable over time - its magnitude has not changed during the last 30 years (Kimura, 2004). Thus, the simplest explanation of this effect, based on differences in socialization and education processes, can not be held. Such differences, of course, do exist, promoting different activities and development of different skills in boys and girls, but they can not account for the whole gender effect in MRT.

The reason of such disparity between women and men still remains unknown, although some possible explanations have been proposed. Firstly, this effect can be attributed to disparate strategies adopted when performing mental rotation task (Roberts & Bell, 2003; Voyer, Voyer & Bryden, 1995). Secondly, men spatial superiority can be explained by brain lateralization pattern, which in turn is under heavy influence of androgens level – hormones associated with many gender differences (Hooven et al., 2004). This assumption is underpinned by cross-cultural stability of gender differences in spatial cognition, suggesting its biological basis (Hughes, 1999). Thirdly, gender impact on mental rotation efficiency can be attributed to familiarization with a computer. MRT is mostly administered as a computerized test. Women often show lack of technical experience, what in turn may hinder their performance. Indeed, Roberts and Bell (2003) demonstrated that a short learning session of computer operation levels their scores in mental rotation task with those obtained by men.

Participants' age also influences mental rotation scores. Kosslyn et al. (1990) discovered that 5-year–olds are already able to transform mental images. This ability develops with age, as older children (8- and 14-year-olds) performed better in the task than younger ones due to general cognitive development, including strategic and control components of information processing. During puberty, mental rotation efficiency similar to adults is reached and strong gender differences emerge (Quaiser-Pohl, Geiser & Lehmann, 2006). However, older participants perform mental rotation task significantly worse (Herzog & Rypma, 1991) – 60-year-olds as compared to 20-year-olds need, on average, 670 ms more for coding, rotation and decision processes (Dror & Kosslyn, 1994). Thus, the relationship between mental rotation efficiency and age of an individual is curvilinear, with decrement occurring along with decline in other cognitive functions (especially in working memory; Baddeley, 1998). It is worth to mention that not all processes involved in reorientation of mental images are affected at the same degree by advanced age (Kosslyn et al., 1990).

The third characteristic that influences mental rotation efficiency is the occupation of an individual. As Ascher (2000) points out, individuals whose job requires manipulation of spatial representations or, more generally, efficacious visual imagination are also found to perform better in mental rotation tasks than individuals regularly engaged in different types of cognitive operations. Likewise, science students (e.g. computer technology, mathematics) are also more skilled in mental rotations of images than their colleagues from arts programs (e.g. social science, humanities; Peters et al., 1995). This difference may be the consequence of natural predispositions, which are later developed during formal education (Hughes, 1999). Everyday experience with handling complex, multidimensional representations may be also the reason of science students proficiency in mental rotation tests (Lehmann, 2001).

Finally, superiority in spatial tasks seems to be connected with preference of specific cognitive style of information processing (Matczak, 1982). "Visualizers" prefer imagery code in the process of object representation, whereas "verbalizers" more frequently use verbal code even to represent visually perceived objects (Paivio, 1986). Individuals labeled as visualizers exhibit significantly higher performance level in mental rotation task than verbalizers (Kozhevnikov, Kosslyn & Shepard, 2005). This preference towards imagery code was also found to accompany the inclination toward science faculties and is more characteristic for men than women, being another possible mediator between individual abilities and cognitive performance in MRT.

The present study

The performance in mental rotation task is likely to be influenced by a vast array of factors. The variables mentioned above moderate one's efficiency of internal images reorientation, indicating intricacy of mental rotation phenomenon. Nevertheless, results obtained so far concerning various determinates of mental rotation efficiency, although detailed and well-replicated, are limited as they refer only to manipulation of neutral, non-affective images. Meanwhile, emotionality aspect of a mental image as one of possible moderators of mental rotation efficiency, has been neglected – most of the previously conducted experiments used abstract, affect-free stimuli that were neither cognitively engaging nor important for the participants. On the contrary, visual imagination was developed to support and aid perception, problem-solving and decision making processes that are concentrated on significant information. Moreover, mental images are associated with emotional states management, regulation and compensation. Thus, it seems plausible to investigate imagination efficiency when it operates on more "ecological", affect-loaded material. Such data is needed, as being complementary to the already gained knowledge about processing of neutral images.

The main aim of presented study was to create and validate emotional version of mental rotation task. Along with the emotional version of MRT, a compatible neutral version was also created to compare shapes of mental rotation curves with regard to stimuli type. Both versions of mental rotation task, thought of as a tool for examining content-bound imaginary processes, were tested in two pilot studies (Experiment 1 and 2) and the obtained results were subsequently replicated in the main study, conducted on a large, individually varied sample (Experiment 3).

Experiment 1

Method

Participants

A total number of 38 volunteers (35 females, 3 males; M_{age} = 19.8 years, SD = 0.7) took part in this study, which was a part of a larger experimental session. All participants were first year psychology students, who received extra course points in return for taking part in the experiment.

Materials

In order to construct new mental rotation task (MRT) in emotional and neutral versions, form identification task (Cohen & Kubovy, 1993; see Introduction) was used, operating on mutants instead of reflected images in negative response condition. Two stimuli appeared simultaneously on the screen. One of them (probe) was rotated by a certain degree against the other (template). The participants' task was to decide whether the stimuli were the same, only rotated (positive response condition) or completely different objects (negative response conditions). Although this form of MRT may yield weaker rotation effect, the rotation rate provided in this procedure seems to be purer than in case of handedness recognition task. According to Koriat et al. (1991), isomers require additional operation of image flipping that takes place after rotation and therefore artificially prolongs overall MRT mean reaction times. Since it is not possible to disentangle the time consumed by rotation and flipping processes, form identification version of MRT was chosen in order to avoid this constraint. This pattern of construction was also inevitable with regard to stimuli that was used in emotional version of MRT (see below).

Neutral version of mental rotation task (N-MRT) utilized both two-dimensional (2D) and three-dimensional (3D) figures as the stimuli. According to the data obtained in the previous studies (see Introduction), it seemed necessary to manipulate the dimensionality factor, since 3D condition can be considered as more difficult than 2D condition. 2D

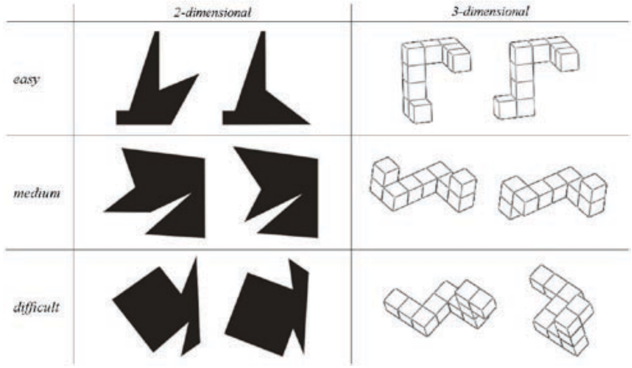

Figure 1. 2D and 3D stimuli used in N-MRT version (Experiment 1).

figures were polygons taken from Vanderplas and Garvin set. Twenty objects, varying in complexity, were chosen arbitrarily. Twelve 3D figures were created by the authors using AutoCAD 2005 application. Mutants used in negative response condition were created by slight modifications of each of stem 2D and 3D shapes. The emergent set of pairs of polygons and stereoscopic figures were subsequently presented to a group of judges consisting of psychology under- and postgraduates (N = 10). They evaluated the difficulty and utility of the stimuli in the context of mental rotation task, using 7-points Likert scale. Based on the obtained scores, three 2D figures and three 3D figures were chosen. All six pairs (see Fig. 1) had similar, high utility in the context of MRT and differed in difficulty.

Black and white photographs, taken from Ekman and Friesen set, served as the stimuli in emotional version of mental rotation task (E-MRT). Faces, depicting emotions, were chosen on the account of their affective impact and saliency. As Helgeson (2002) suggested, there is a significant difference in relative expressiveness with regard to actors' gender, favoring females. Thus, only women photos were used to create E-MRT. Three (out of eight) actresses were chosen due to their differed expressiveness, as assessed by the same group of judges as previously (see description of N-MRT construction). The manipulation of expressiveness in E-MRT was intended to be analogous to stimuli difficulty manipulation in N-MRT, with the highest expressiveness condition of E-MRT reflecting the easiest condition of N-MRT. Only sadness and anger were selected as depicted emotions (see Fig. 2). According to the results obtained with the use of priming paradigms (Ohme, 2003), these emotions differ in respect to legibility and impact on the perceiver, resulting in higher processing speed for anger. Unfortunately, positive emotions were not chosen, as they all bore the same facial expression. Sadness and anger were paired with each other in negative response condition. Regardless of "the same"/"different" trial, two simultaneously presented photos always depicted the same actress.

Six angular orientations were used, ranging from 0^{o} to 300^{o}, in 60^{o} increment. Stimulus appearing on the left side of the screen was the template in canonic (upright)

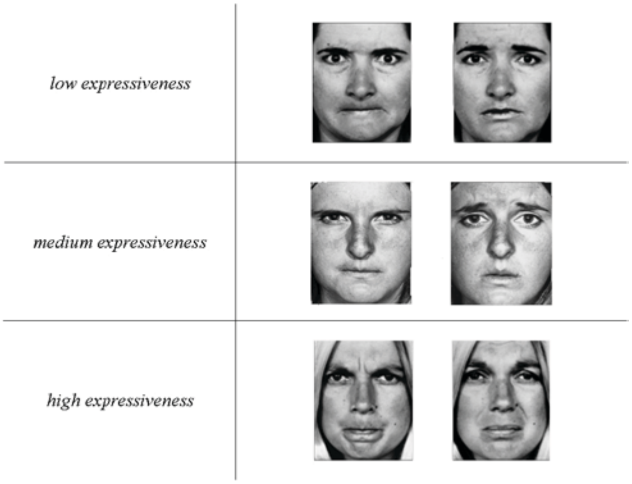

Figure 2. Emotional faces used as stimuli in E-MRT (Experiment 1).

orientation, whereas stimulus presented on the right side was the probe demanding reorientation. Rotation was carried out only in plain of presentation. N-MRT consisted of 72 trials (36 two-dimensional, 36 three-dimensional). E-MRT also consisted of 72 trials.

Variables

There were four independent variables in neutral version of the MRT task: (1) angular disparity between the template and the probe (from 0º to 300º, in 60º increment); (2) stimuli dimensionality (2D versus 3D); (3) stimuli difficulty (easy, medium or difficult); and (4) response condition (negative versus positive). There were also four independent variables in emotional version of the MRT task: (1) diversity between the template and the probe (from 0º to 300º, in 60º increment); (2) emotion type (anger versus sadness); (3) emotion expressiveness (low, medium or high); and (4) response condition (negative versus positive).

Two measures of task performance were registered: (1) reaction time of correct response; and (2) accuracy of responses.

Procedure

The participants performed the whole MRT in the fixed order: 2D N-MRT, then 3D N-MRT, and E-MRT at the end. Each part of mental rotation test was preceded by a short training (6 trials per part), carried out on stimuli not used in the main task. There were also short breaks for resting purpose between performance periods of the subsequent parts of experimental task.

Results

Surprisingly, mental rotation effect was not obtained with the use of neutral stimuli. As far as RTs in N-MRT version were concerned, only two significant differences with regard to angular disparity of displayed objects were

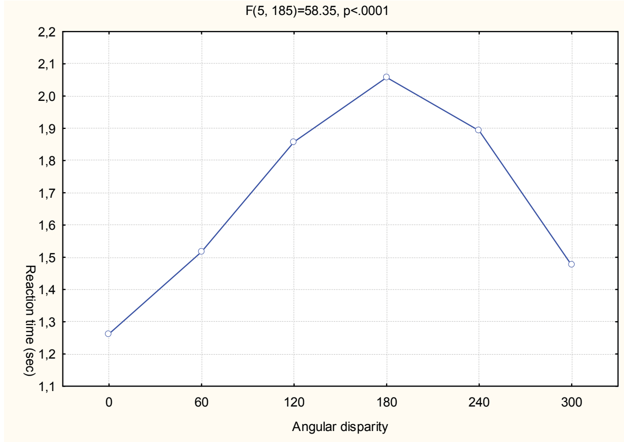

Figure 3. Mental rotation effect for E-MRT version (Experiment 1).

observed. Planned comparisons revealed that RTs were significantly shorter in lack of rotation condition (0º) in comparison to 60° angular difference condition ($p < .00001$) and in 300° condition in comparison to 240° probe rotation ($p < .00002$). The flatness of rotation curve was also evident when 2D and 3D conditions were analyzed separately.

Stimuli difficulty and response type manipulations were completely unsuccessful. Increasing stimulus complexity did not trigger longer reaction times and mean RTs were comparable in both response conditions. The latter was true regardless of stimuli dimensionality and when 2D and 3D experimental conditions were analyzed separately. However, mean reaction time was significantly longer in 3D condition in comparison to 2D condition (890 ms difference; $F[1,37] = 31.74$, $p < .0001$, $\eta_p^2 = .46$). The overall accuracy was found to be similar (75% of correct responses) in both stimuli dimensionality conditions.

Classic mental rotation curve was observed with the use of emotional stimuli ($F[5,185] = 58.35$, $p < .0001$, $\eta_p^2 = .61$; see Fig. 3). As far as reaction times in E-MRT version were taken into account, planned comparisons revealed that all differences in RTs between subsequent angular orientations were significant (p at least 0.008).

Main effect of the response type variable was also obtained. Surprisingly, positive response condition demanded more time than negative one (230 ms difference; $F[1,37] = 16.86$, $p < .0001$, $\eta_p^2 = .31$). The significant interaction between expressiveness and type of emotion was observed ($F[2,74] = 17.43$, $p < .0001$, $\eta_p^2 = .32$), although main effects of both manipulation variables were insignificant. As far as RTs were concerned, the clear difference was observed only for photos of medium expressiveness. In this experimental condition, it took the participants significantly more time (p less than .002) to react when anger was the template. Expressiveness also interacted with type of required response ($F[2,74] = 18.84$; $p < .0001$, $\eta_p^2 = .34$). The positive response condition generated the longest RTs in low expressiveness trials, while the negative response was the fastest to photos of highly expressive actress.

Finally, mean reaction time of responses in a single trial was shorter for emotional stimuli than for neutral ones (1.62 versus 3.48 sec; $p < .0001$). The overall accuracy in E-MRT version of the mental rotation task was greater (91% of correct responses) in comparison to N-MRT (75% of correct responses).

Discussion

Unfortunately, N-MRT did not meet the requirements for standard mental rotation procedure, as no relationship was found between reaction times and angular disparity of the stimuli. The neutral version of MRT task used in Experiment 1 could have been too difficult to show clear MRE, but the accuracy rates far above chance level suggest otherwise. Instead, it is possible that 2D and 3D stimuli used in this task do not require mental rotation at all. The results of the previously conducted experiments (see Introduction) suggest that participants do not rotate the images when simpler, non-rotational strategies can be adopted (Folk & Luce, 1987). Thus, completely new version of N-MRT had to be constructed in a subsequent study. As there were almost no differences between 2D and 3D experimental conditions, maintaining this distinction seemed unnecessary and 3D stimuli were designated for elimination.

On the other hand, the E-MRT version of mental rotation task met most of the requirements. Response times increased to 180^o and then decreased back to 300^o, providing classic curvilinear RT/angular disparity function. It is difficult to assess the efficiency of expressiveness and emotion type manipulations, as their interactive effects were only observed. Possibly, the chosen photos of medium expressiveness actress are responsible for this lack of main effects. The actress' anger expression could have caused a kind of attentional bias which hindered other manipulations. It was decided to remove this actress photos from the set of the stimuli in the subsequent study. Finally, a surprising effect was obtained involving the response type. Positive response trials ("the same") took longer time to react than negative response trials ("different"), while usually the opposite holds true (Farell, 1985). The reason of this incongruence remains unknown, but hypothetical explanations can be launched only if this effect replicates in another study. Otherwise, it can be treated just as an artifact caused by either too small sample or specificity of the used stimuli. Overall, E-MRT proved to be an appropriate tool to assess various aspects of mental rotation process. Thus, Experiment 2 was devoted to construct N-MRT version that meets the requirements for standard mental rotation procedure.

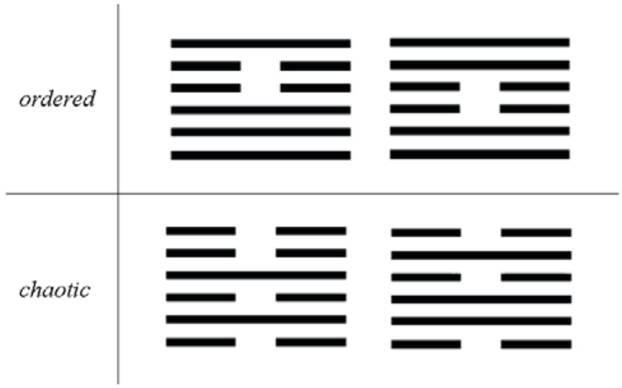

Figure 4. Hexagrams used as stimuli in new N-MRT (Experiment 2).

Experiment 2

Method

Participants

A total number of 33 volunteers (22 females, 11 males; M_{age} = 35.75 years, SD = 10.44) took part in the experiment. Participants were recruited from various groups and differed with respect to age, place of residence and occupation, resulting in a rather heterogeneous convenience sample. The information about the performance in the mental rotation tests was the only gratification for the participants.

Materials

In this study, new neutral version of MRT was tested. Instead of 2D polygons, Chinese hexagrams were used. The signs consist of six horizontal lines (continuous or discontinuous), arranged in a total of 64 possible combinations. All hexagrams are similar in shape and identical in size, which may impede using perceptual comparison solving strategies. Sterczyński and Kolańczyk (2001) evaluated these signs on emotional (pleasant versus unpleasant) and cognitive (chaotic versus ordered) scales. In the new version of neutral mental rotation task hexagrams judged as neither pleasant nor unpleasant were chosen. The score in the cognitive scale, in turn, was useful to assess difficulty of the stimuli. Chaotic signs were assumed to be difficult, whereas ordered ones were taken as simple. However, "mutants" could not be created simply by changing the lines arrangement, as it also would change the identity and emotionality of such sign. Instead, two more hexagrams were chosen to be mutants. They were both emotionally neutral, but differed significantly with regard to the score on the cognitive scale. They also slightly differed in shape from the templates. These two hexagrams were paired with templates for the purpose of the negative response condition (see Fig. 4).

Unfortunately, due to stimuli specificity, N-MRT version is not fully compatible with E-MRT. One of the ordered hexagrams is symmetric – as a result its 0^o and

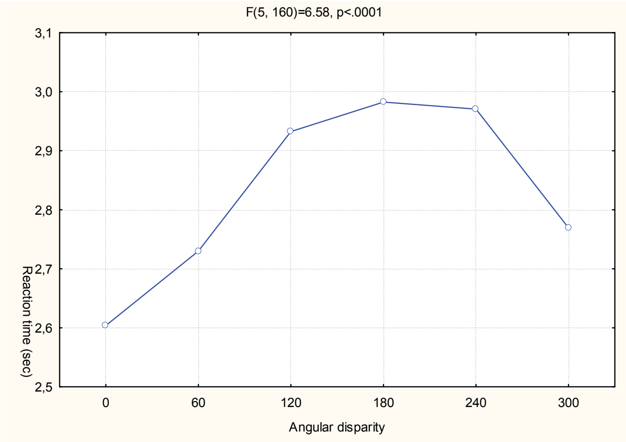

Figure 5. Mental rotation effect for hexagram-based N-MRT version (Experiment 2).

180° angle orientations are exactly the same. The use of such stimulus in mental rotation task is hazardous, as it may misshape mental rotation curve. Nevertheless, such risk was undertaken as no other ordered and emotionally neutral hexagrams could have been chosen. Additionally, as the result of setup error, each trial was repeated twice in random order. The latter was discovered no sooner than after conducting the third study. Thus, it could not be corrected. Nevertheless, setup error influence on overall performance was carefully examined in Experiment 2 and 3.

Six angular orientations (0°, 60°, 120°, 180°, 240°, 300°) remained the same. The whole N-MRT task consisted of 48 trials. Stimulus appearing on the left side of the screen was the template in canonic (upright) orientation, whereas stimulus presented on the right side was the probe demanding reorientation. Rotation was carried out only in the plain of presentation.

Variables

There were four independent variables: (1) angular orientation of rotated stimulus (from 0° to 300°, in 60° increment); (2) stimuli difficulty (chaotic versus ordered); and (3) response condition (negative versus positive); (4) trial repetition. Two measures of task performance were registered: (1) reaction time of correct response; and (2) accuracy of responses.

Procedure

The N-MRT was preceded by a short training (6 trials), carried out on stimuli not used later in the main task. The E-MRT was not used this time.

Results

The mental rotation effect was observed ($F[5,160] = 6.58$, $p < .0001$, $\eta_p^2 = .17$; see Fig. 5). Reaction times of correct responses depended on angular disparity between the two displayed characters. Mean RT increased until 180° angular disparity and subsequently decreased after exceeding this value. Almost all simple effects with regard to angular disparity variable appeared to reach significance level (p at least 0.04). Only two differences were insignificant. The participants responded with the same speed in 120°/180° angular difference condition as well as in 180°/240° angular difference condition.

Stimuli difficulty variable yielded strong main effect ($F[1,32] = 51.42$, $p < .00001$, $\eta_p^2 = .62$). On average, the participants responded 550 ms faster in trials with ordered signs as the template in comparison trials when chaotic hexagram was displayed. Positive response condition appeared again more demanding than the negative one – 200 ms more was needed to respond in the former case ($F[1,32] = 6.43$, $p < .02$, $\eta_p^2 = .17$). Even repetition factor yielded main effect ($F[1,32] = 18.35$, $p < .002$, $\eta_p^2 = .36$). The second response to exactly the same trial was approximately 400 ms shorter than during first encounter. Finally, mean time of response in a single trial was shorter for hexagrams in comparison to previous neutral version of mental rotation task (2.83 sec versus 3.48 sec). Moreover, the overall average accuracy was higher than obtained with the use of former version of N-MRT, now reaching 95% of correct responses.

As the sample differed with regard to age, additional analysis was conducted with this variable as an independent factor. It was discovered that younger participants (median split; $M_{age} = 27.23$ years) outperformed older ones ($M_{age} = 44.81$ years), being significantly faster in their responses (difference 1000 ms; $p < .002$). However, they were also less accurate (5% difference; $p < .01$). The impact of gender on mental rotation effect could not be analyzed, as men outnumbered women in the tested sample.

Discussion

The new N-MRT yielded all expected main effects. Mental rotation curve was observed, although slightly asymmetric and with two angular differences found insignificant. It is possible that the sample size was too small to obtain stronger simple effects. Stimuli difficulty manipulation was successful – chaotic hexagrams prolonged reaction times in comparison to the ordered ones. The separate analyses conducted only on RTs in trials with symmetric signs revealed the same effects as analyses performed regardless of stimuli difficulty. The symmetry of ordered hexagram seemed not to have any negative influence on the obtained results, thus it was decided to use it also in the main study (Experiment 3). Mean reaction times as well as mean accuracy in hexagram-based N-MRT were also similar to those obtained with the use of E-MRT in Experiment 1.

The obtained results also confirmed the suggestion that the average age of participants played the crucial role in determining mental rotation efficiency. As it was discovered, older participants performed poorly when compared to the younger ones. There was a huge difference in average age of participants in the two above described experiments (19.8 versus 35.75 years). Age differences may account at least partly for the observed differences in mental rotation effect. As such, age variability should be taken into account (if possible) when between-group performance level comparisons are to be conducted. The obtained results also suggest that the age of participants may moderate speed/accuracy trade-off. Younger participants seem to favor speed, whereas older participants tend to trade it for accuracy.

Finally, new version of N-MRT was also found to be susceptible to training and task automatization. Repetition of test trials shortened significantly reaction times. When both versions (N-MRT and E-MRT) of mental rotation task are performed subsequently, the order of the task effect may influence reaction times obtained in the version completed as the second due to practice transfer. To eliminate such confounding factor, counterbalancing procedure should be introduced.

Experiment 3

Method

Participants

A total number of 136 volunteers took part in the last experiment, which was a part of extended research on cognitive correlates of alexithymia. Participants were recruited from two groups: sobering alcoholics with no cognitive impairment (N = 68; 52 males, 16 females; M_{age} = 44.22 years, SD = 10.19) and non-drinking adults (N=68; 52 males, 16 females; M_{age} = 39.60 years, SD = 9.91), as it was necessary from the whole project's point of view. Both groups were matched on demographic variables, including education level, thus creating homogeneous sample. The only gratification for the participants was the information about their performance in the cognitive tests and personality questionnaires.

Materials

Both created versions of MRT, as described above (E-MRT; Experiment 1; N-MRT; Experiment 2), were used, with modifications suggested in the Discussion sections. Thus, out of two created neutral versions of MRT, the hexagram-based one was utilized. Emotional version of mental rotation task (E-MRT) was shortened by exclusion of medium expressiveness photos from the set of stimuli.

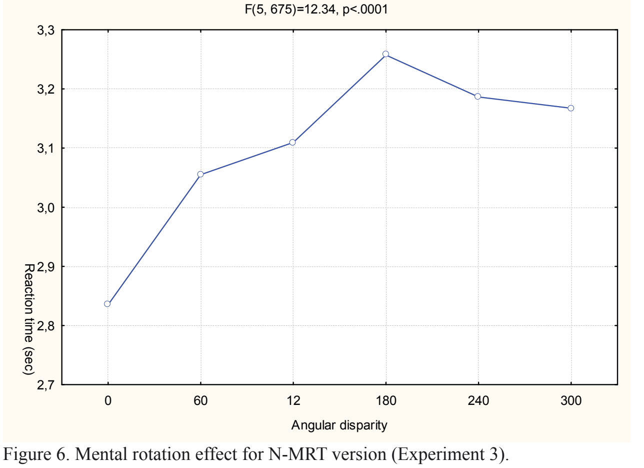

Figure 6. Mental rotation effect for N-MRT version (Experiment 3).

Variables

There were four independent variables in N-MRT: (1) angular disparity between the template and the probe (from 0º to 300º, in 60º increment); (2) stimuli difficulty (chaotic versus ordered); and (3) response condition (negative versus positive); (4) trial repetition. There were also four independent variables in E-MRT task: (1) angular disparity between the template and the probe (from 0º to 300º, in 60º increment); (2) emotion type (anger versus sadness); (3) emotion expressiveness (low versus high); and (4) response condition (negative versus positive).

Two measures of task performance were registered: (1) reaction time of correct response; and (2) accuracy of responses.

Procedure

Each of the two mental rotation task versions consisted of 48 trials preceded by 6 trials of training, carried out on stimuli not used in the main task. The order of completing the versions was randomized and balanced, with 68 participants beginning with N-MRT and the other 68 starting from E-MRT. There were short breaks for resting purpose introduced between performance periods of the subsequent parts of MRT.

The participants also completed two personality questionnaires and two creativity tests. The results concerning individual differences in MRT performance with regard to personality and creativity variables are described elsewhere (Czernecka & Szymura, 2008).

Results

Unfortunately, not all results obtained in Experiment 2 for N-MRT were replicated in Experiment 3, although exactly the same neutral version of mental rotation task was employed in both studies. MRE was obtained (F[5,675] = 12.34, p < .0001, η_p^2 = .08; see Fig. 6). However, mental rotation curve flattened when angular difference between

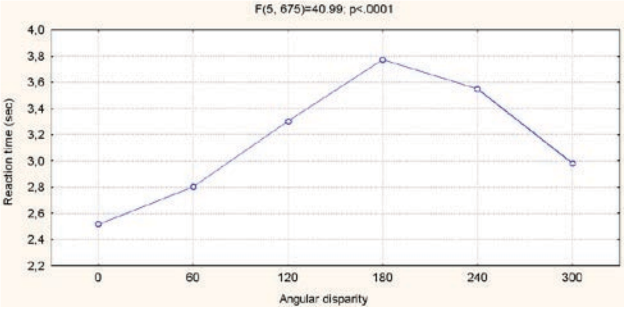

Figure 7. Mental rotation effect for E-MRT version (Experiment 3).

the two presented hexagrams exceeded 180°. Planned comparison analyses revealed that only differences between 0°/60° angular difference condition and between 120°/180° angular difference condition were significant ($p < .001$ and $p < .002$, respectively).

The experimental manipulation of difficulty of the stimuli used in N-MRT was again successful. Mean reaction time in trials with chaotic hexagram as the template was 690 ms longer in comparison to mean RT in trials with ordered character ($F[1,135] = 118.42$, $p < .0001$, $\eta_p^2 = .47$). Once more, positive response condition was found to be more time-consuming than the negative one (difference 260 ms; $F[1,135] = 26.58$, $p < .0001$, $\eta_p^2 = .16$. However, the main effect of response condition was salient only in trials depicting chaotic hexagrams. As far RTs in negative response condition were taken into account, no mental rotation effect was observed. Trial repetition variable also yielded main effect ($F[1,135] = 113.09$, $p < .0001$, $\eta_p^2 = .46$). Mean reaction time was shorter (630 ms) during the second response to exactly the same pair of stimuli. Finally, mean response time in a single trial as well as average accuracy in N-MRT were similar to those obtained in Experiment 2 (3.10 sec and 95% of correct responses, respectively).

The expected relationship between reaction times and angular disparity was obtained with the use of E-MRT ($F[5,675] = 40.99$, $p < .0001$, $\eta_p^2 = .23$; see Fig. 7). As far as RTs were concerned, almost all simple effects regarding angular difference variable appeared to reach significance level. Only in 120°/180° angular difference condition the participants responded with the same speed ($p < 0.08$).

Expressiveness of the actress was found to influence speed of responses in reversed to the expected manner ($F[1,135] = 82.87$, $p < .0001$, $\eta_p^2 = .38$). Photos of a highly expressive actress were processed approximately 450 ms slower than low expressive pictures. In agreement with results obtained in Experiment 1, trials with anger on a template photo provided faster reactions than trials with sadness presented on template picture (difference 170 ms; $F[1,135] = 7.68$, $p < .006$, $\eta_p^2 = .05$). Again, positive response condition was found to be more difficult ($F[1,135] = 43.076$, $p < .0001$, $\eta_p^2 = .24$). Trials with "the same" being the correct response demanded approximately 750 ms more than trials where "different" was the correct answer. Finally, mean response time in a single trial in E-MRT equaled 3.15 sec. This is comparable to N-MRT average RTs, but is two times longer than in the same E-MRT version used in Experiment 1 (1.62 sec). The overall accuracy, on the other hand, was almost the same as the one obtained in Experiment 1 (90% of correct responses).

Just as in Experiment 1, the sample varied with regard to age, thus additional analysis of this factor was conducted. The participants were split by median in two groups that were subsequently compared on single trial mean response time and overall task accuracy. The rate of correct responses was the same for younger (mean age 32.81 years) and older (mean age 49.73 years) participants. There was a difference in mean response time – younger participants were faster than the older ones in both N-MRT (2.56 sec versus 3.49 sec; $p < .00001$) and E-MRT (2.69 sec versus 3.52 sec; $p < .003$). The impact of gender on mental rotation effect, again, could not be analyzed.

Discussion

In the main experiment almost all important results obtained in Experiment 1 and Experiment 2 were replicated. MRE effect was observed with the use of N-MRT (but only to 180° difference in template and probe orientation) as well as with the use of E-MRT. The relative weakness of mental rotation effect as obtained with the use of N-MRT can be connected with the type of mental rotation test used, namely form identification task. According to Cohen and Kubovy (1993), only handedness recognition task requires mental rotation of object, while the other type of MRT is usually solved using semi-rotational or perceptual strategies. It is also possible that hexagrams do not need to be represented as a complete mental image and partial representation consisted of only a few features is enough to provide an answer, which in turn may distort the obtained relationships. Additionally, completely flat shape of the mental rotation curve in negative response condition suggests that some trials were solved on the basis of mere comparison of salient features. Nevertheless, the shape of the rotation curve, although far from ideal, was more satisfactory in the case of hexagrams than in the case of polygons, used in Experiment 1.

As assumed, all manipulations influenced reaction times in N-MRT version. Trials with chaotic hexagrams demanded more time to be solved than the ones with ordered hexagrams. The rate of rotation is probably the same in both cases, but the process of constructing more complex or irregular image requires more time (Shepard & Metzler, 1988). The effect of trial repetition is consistent with data obtained in the previous studies concerning training (see Introduction). The only surprising outcome, obtained with the use of N-MRT, was the positive response condition appearing to be more difficult than the negative one. Usually, the opposite is observed. Nevertheless, according to Farell (1985), such results can be observed when differences between the template and the probe are large and salient. This is the case of hexagrams that can be easily distinguished from each other in negative response condition. Thus, this surprising effect, being generally incongruent with data from other experiments, is the consequence of the used stimuli.

E-MRT proved to be an appropriate tool to assess various aspects of mental rotation process. The classic mental rotation curve was observed with the use of emotional stimuli. The obtained relationship between RTs and angular disparity of two photos depicting faces can be interpreted in favor of hypothesis that face pictures are being normalized to upright, canonical position before comparison. This supports the notion that human faces, apart from their undoubted specificity, are represented and processed in the same manner as neutral objects. The results obtained with the use of E-MRT were more satisfying than data gathered with the use of N-MRT. This may be connected to relative strength of canonical face position. Contrary to abstract figures, a face has one "correct" spatial position that is necessary for recognition to occur. That can be the reason why inverted faces are so difficult to process (the face inversion effect; e.g. Rossion & Gauthier, 2002) and need to be rotated to "upright" position. In this case, full rotational strategy seems to be not only more economical but also inevitable, as the task is rather difficult to be solved otherwise.

As expected, all manipulation variables yielded strong main effects. Anger expressed on the template photo triggered more rapid reactions than sadness. It can be explained by special informational value of anger. Anger is one of the most important indicators of upcoming danger. Thus, detection of anger expression among other basic emotions is relatively easy (Hansen & Hansen, 1988). Anger is also well recognized when its presentation is degraded or subliminal (Ohme et al., 2001). The expressiveness factor also diversified reaction times, but surprisingly photos of a highly expressive actress generated longer response latencies. This result can be explained in terms of attentional bias. Emotions presented by this actress could be so clear that trials using her photos intensified and captured the participants' attention, resulting in longer response times. Negative emotions are also highly arousing – if it was the case, it could disrupt performance by reducing the capacity of working memory (Humphreys & Revelle, 1984). Nevertheless, these explanations are hypothetical and demand further empirical exploration. Finally, positive response condition appeared more time-consuming than the negative one, just as it was observed with the use of N-MRT version. The reason is probably the same, as two basic emotions are easy to be distinguished. But again, this result demands further verification in experiment with the use of basic and complex emotional expression stimuli.

Finally, the age variable again moderated mental rotation effects. Younger participants provided faster responses than older ones in both MRT conditions, although the overall accuracy in both groups was this time the same. When compared to results obtained in Experiment 1, it appears that with increasing age response time prolongs, while accuracy rises to a certain point and stays constant. It seems that age afflicts mainly the speed of cognitive processes, while their precision is intact or even increases, due to the further development of strategic components and cognitive control over information processing. In any case, age is a potential confounding factor and must be acknowledged in studies concerning mental rotation effect.

In the three experiments, we aimed to verify the utility of new mental rotation test that uses both neutral and emotional stimuli. The obtained data can be interpreted largely on behalf of N-MRT and E-MRT tasks. They both proved to be an appropriate tools to assess various aspects of mental rotation process, as both met the criteria set for such a procedure. Surprisingly, completely new E-MRT task worked better than N-MRT task, constructed on the base of the data previously gathered in various experiments. Nonetheless, further experiments are needed to replicate the stability of some rather surprising and incongruent with literature findings (e.g. expressiveness and response condition effects). Generally, it seems that the presented procedures may be used to study content-dependent imagination, although results from N-MRT must be interpreted with caution until its validity is thoroughly replicated.

What is more important, E-MRT procedure opens new possibilities in investigating imagination-emotion relationship. On the one hand, it enables studying groups or individuals who are claimed to have constricted or disturbed imagery processes (e.g. alexithymic individuals; Czernecka & Szymura, 2008). The results obtained with the use of N-MRT/E-MRT may be used to judge the severity as well as generality of such dysfunction. On the other hand, the procedure can also be utilized in studying cognitive correlates of emotionality traits like anxiety or neuroticism. As both of these factors are known to disrupt cognitive performance, it is reasonable to expect same differences with respect to imagery efficiency. Finally, the MRT procedure as described in this article can be used to estimate imagination capacity along with its properties when different types of stimuli are taken into consideration.

References

Ascher, E. A. (2000). Mental rotation in artists and non-artists. Colgate *University Journal of Sciences*, 32, 149-153.

Baddeley, A. (1998). *Pamięć. Poradnik użytkownika*. [Memory: User's

Handbook] Warszawa: Prószyński i S-ka
Bauer, B., Jolicoeur, P. (1996). Stimulus dimensionality effects in mental rotation. *Journal of Experimental Psychology: Human Perception and Performance, 22*, 1, 82-94.
Bethell-Fox, C. E., Shepard, R. N. (1988). Mental rotation of stimulus complexity and familiarity. *Journal of Experimental Psychology: Human Perception and Performance, 14*, 1, 12-23.
Cohen, D. J., Blair, C. (1998). Mental rotation and temporal contingencies. *Journal of the Experimental Analysis of Behavior, 70*, 203-214.
Cohen, D. J., Kubovy, M. (1993). Mental rotation, mental representation, and flat slopes. *Cognitive Psychology, 25*, 3, 351-382.
Collins, D. W., Kimura, D. (1997). A large sex difference on a two-dimensional mental rotation task. *Behavioral Neuroscience, 111*, 4, 845-849.
Cooper, L. A. (1975). Mental rotation of random two-dimensional shapes. *Cognitive Psychology, 7*, 20-43.
Cooper, L. A., Shepard, R. N. (1973). The time required to prepare for a rotated stimulus. *Memory and Cognition, 1*, 3, 246-250.
Corballis, P. M., Corballis, M. C. (1993). How apparent motion affects mental rotation: Push or pull? *Memory and Cognition, 21*, 458-466.
Czernecka, K., Szymura, B. (2008). Alexithymia – imagination – creativity. *Personality and Individual Differences, 45*, 445-450.
Dror, I. E., Kosslyn, S. M. (1994). Mental imagery and aging. *Psychology and Aging, 9*, 1, 90-102.
Farell, B. (1985). „Same“-„Different“ judgements: a review of current controversies in perceptual comparison. *Psychological Bulletin, 98*, 3, 419-456.
Folk, M. D., Luce, R. D. (1987). Effects of stimulus complexity on mental rotation rate of polygons. *Journal of Experimental Psychology: Human Perception and Performance, 13*, 3, 395-404.
Humphreys, M. S., Revelle, W. (1984). Personality, motivation, and performance: a theory of the relationship between individual differences and information processing. *Psychological Review, 91*, 153-184.
Helgeson, V. S. (2002). *The psychology of gender*. New Jersey: Pearson Education Inc.
Heil, M., Rösler, F., Link, M., Bajric, J. (1998). What is improved if a mental rotation task is repeated - the efficiency of memory access, or the speed of a transformation routine? *Psychological Research, 61*, 2, 99-106.
Hertzog, C., Rypma, B. (1991). Age differences in components of mental-rotation task performance. *Bulletin of the Psychonomic Society, 29*, 3, 209-212.
Hooven, C. K., Chabris, C. F., Ellison, P. T., Kosslyn, S. M. (2004). The relationship of male testosterone to components of mental rotation. *Neuropsychologia, 42*, 782-790.
Hughes, K. K. (1999). *Effects of perceived gender role on gender differences in mental rotation*. Irvine: unpublished dissertation.
Kimura, D. (2004). Human sex differences in cognition: fact, not predicament. *Sexualities, Evolution and Gender*, *6*, 45–53.
Koriat, A., Norman, J., Kimchi, R. (1991). Recognition of rotated letters: extracting invariance across successive and simultaneous stimuli. *Journal of Experimental Psychology: Human Perception and Performance, 17, 2,* 444-457.
Kosslyn, S. M., Margolis, J. A., Barrett, A. M., Goldknopf, E. J., Daly, P. F. (1990). Age differences in imagery abilities. *Child Development, 61*, 995-1010.
Kozhevnikov, M., Kosslyn, S. M., Shephard, J. M. (2005). Spatial versus object visualizers: A new characterization of visual cognitive style. *Memory and Cognition, 33*, 710-726.
Lehmann, W. (2001). Group differences in mental rotation. *Magdeburger Arbeiten zur Psychologie, 2,* 1-18.
Matczak, A. (1982). *Style poznawcze*. [Cognitive styles] Warszawa: PWN.
McMullen, P. A., Jolicoeur, P. (1992). The reference frame and effects of orientation on finding the top of rotated objects. *Journal of Experimental Psychology: Human Perception and Performance, 18,* 807-820.
Ohme, R. K. (2003). *Podprogowe informacje mimiczne*. [Subliminal facial expression information]. Warszawa: PAN, SWPS.
Ohme, R. K., Augustynowicz M., Kukliński K. (2001). Przedświadome rozróżnianie ekspresji mimicznej. [Preconscious distinguishing of facial expressions]. *Studia Psychologiczne*, *39*, 29-40.
Paivio, A. (1986). *Mental representations: a dual-coding approach.* New York: Oxford University Press.
Pavlik, P., Anderson, J. (2002). *Mental rotation transfer*. Proceedings of 34th Annual Meeting of the Cognitive Science Society, 8-10 August, Fairfax.
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, 1,* 39-58.
Quaiser-Pohl, C., Geiser, C., Lehmann, W. (2006). The relationship between computer-game preference, gender, and mental-rotation ability. *Personality and Individual Differences, 40, 3,* 609-619.
Roberts, J. E., Bell, M. A. (2003). 2- and 3-dimensional mental rotation tasks lead to different parietal laterality for men and women. *International Journal of Psychophysiology, 50,* 235-246.
Rossion, B., Gauthier, I. (2002). How does the brain process upright and inverted faces? *Behavioral and Cognitive Neuroscience Reviews, 1, 1,* 62-74.
Shepard, R. N., Metzler, J. (1971). Mental rotation of three-dimensional objects. *Science, 171*, 701-703.
Shepard, S., Metzler, D. (1988). Mental rotation: effects of dimensionality of objects and type of task. *Journal of Experimental Psychology: Human Perception and Performance, 14, 1,* 3-11.
Sterczyński, R., Kolańczyk, A. (2001). Rola bodźca docelowego w paradygmacie wizualnego poprzedzania. [The role of a target in the paradigm of affective visual priming] *Studia Psychologiczne, 39,* 81-98.
Voyer, D., Voyer S., Bryden, M. P. (1995). Magnitude of sex-differences in spatial abilities: A metaanalysis and consideration of critical variables. *Psychological Bulletin, 117,* 250-270.