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Experimental Aging Research

An International Journal Devoted to the Scientific Study of the Aging Process

ISSN: 0361-073X (Print) 1096-4657 (Online) Journal homepage: www.tandfonline.com/journals/uear20

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To cite this article: Martina Rahe, Vera Ruthsatz, Petra Jansen & Claudia Quaiser-Pohl (2018) Influence of sex-stereotyped stimuli on the mental-rotation performance of elderly persons, Experimental Aging Research, 44:4, 284-296, DOI: 10.1080/0361073X.2018.1475156

To link to this article: https://doi.org/10.1080/0361073X.2018.1475156

Published online: 21 May 2018.

EXPERIMENTAL AGING RESEARCH
2018, VOL. 44, NO. 4, 284–296
https://doi.org/10.1080/0361073X.2018.1475156

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Influence of sex-stereotyped stimuli on the mental-rotation performance of elderly persons

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ABSTRACT

Background: In mental-rotation tests with cube figures as rotational objects, differences in favor of men are often found (Voyer, Voyer, & Bryden, 1995). Mental-rotation performance often declines with age (Jacewicz & Hartley, 1987), but sex differences usually remain (Herman & Bruce, 1983).

Methods: In this study, male- and female-stereotyped objects were used as rotational stimuli in a mental-rotation paper and pencil test (Ruthsatz, Neuburger, Rahe, Jansen, & Quaiser-Pohl, 2017) for elderly participants (age: 57–88 years).

Results: Overall, no sex differences for mental-rotation performance were found, whereas a significant interaction of sex and stimulus material revealed better performance for own-sex objects (η^2 = .070). A significant negative correlation between mental-rotation performance and age could be found (r = –.384).

Conclusions: It seems to be easier to perform mental-rotation with objects that persons are more familiar with. There is a decrease in mental-rotation accuracy as well as in the processing speed for the older participants.

ARTICLE HISTORY
Received 30 September 2016
Accepted 30 October 2017

Introduction

Sex differences in mental-rotation performance

Sex differences favoring men are usually found in spatial abilities, especially in psychometric mental-rotation tests (Peters et al., 1995; Voyer, Voyer & Bryden, 1995). Among other reasons, these differences are assumed to be genetically (Quinn & Liben, 2014), hormonally (Alexander & Son, 2007; Hampson, 1990), or psychosocially (Moè & Pazzaglia, 2006) caused. Cognitive performance often decreases when negative stereotype threats are initiated (Steele & Aronson, 1995). Stereotype thread is defined, as being at risk of confirming a negative stereotype that is applicable in the given situation (Steele & Aronson, 1995). If someone believes that a group he or she belongs to has worse abilities in a specific domain than other groups, then that person can be affected by stereotype thread. This can lead to worse performance in tests requesting this specific domain (Steele & Aronson, 1995). On the contrary, stereotype lift effects can occur when someone beliefs that an outgroup the person did not belong to has a disadvantage in a certain task (Walton

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& Cohen, 2003). This can result in a better performance (Walton & Cohen, 2003). One of the stereotype threat explanations is the activation of sex stereotypes in spatial ability tests. They can lead to sex differences particularly when participants think that males are better at this task (Hausmann, Schoofs, Rosenthal & Jordan, 2009; Neuburger, Jansen, Heil & Quaiser-Pohl, 2012). Furthermore, individually manipulated confidence can lead to better (high confidence) or worse (low confidence) performance in mental-rotation tests (Estes & Felker, 2012). In a recent meta-analysis, Doyle and Voyer (2016) showed that manipulations with a stereotype thread to females led to worse performance on math but not on spatial tasks, whereas stereotype lift effects were significant for females on spatial but not on math tasks.

Other reasons for differences favoring males are assumed to be variations in specific activities, like computer games (Cherney, 2008), a specific coordinative motor training (Blüchel, Lehmann, Kellner & Jansen, 2013), or spatial activities (Baenninger & Newcombe, 1989; Nazareth, Herrera & Pruden, 2013).

Task characteristics

Additional reasons for the male advantage in mental-rotation performance might be task characteristics. For picture plane rotations, the performance of adults is usually better than for rotations in depth (Gauthier et al., 2002), thus mental rotations in picture plane seem to be less difficult than those in depth. The difficulty of the task could partly be responsible for sex differences.

In a study with elementary school children, Ruthsatz, Neuburger, Jansen, and Quaiser-Pohl (2014) found boys outperforming girls only for the more difficult 3D rotation of cube figures, while there were no differences for 2D rotations. If the difficulty in 2D tests is varied, results show sex differences as high as these in 3D Vandenberg tests for the more difficult items (Collins & Kimura, 1997). Comparing more difficult occluded items in which parts of the cube figures are occluded with non-occluded items, the sex difference for the occluded items was larger than for the less difficult non-occluded ones (Bors & Vigneau, 2011).

Another task characteristic next to rotational axis and difficulty is different rotational stimuli that could lead to different results in mental-rotation performance. The cube figures used by Shepard and Metzler (1971) and Vandenberg and Kuse (1978) resemble LEGO® bricks or construction toys and are perceived as more male-stereotyped (Ruthsatz, Neuburger, Jansen & Quaiser-Pohl, 2015). The male-stereotyped characteristic of the cube figures is supposed to be one of the reasons for sex differences. Using human figures instead of cube figures as rotational objects, the performance of females usually increases (Alexander & Evardone, 2008; Doyle & Voyer, 2013).

The time required for the encoding, mental rotation, and comparison of familiar stimuli is shorter than for more unfamiliar objects (Bethell-Fox & Shepard, 1988; Koriat & Norman, 1985). Using both cube figures and human figures as rotational objects, the sex difference of the cube figure test is reduced when using human figures (Alexander & Evardone, 2008; Doyle & Voyer, 2013). In both studies, participants showed better performance with human figures than with cube figures. Particularly women seem to benefit from rotational objects that are less male stereotyped. Ruthsatz et al. (2014) found sex differences favoring boys only in tasks with cube figures rotated in depth, which were rated as male stereotyped; the use of more female-stereotyped pellet figures did not lead to sex differences. Thus, familiarity of the rotational objects could lead to better mental-rotation performance and reduce sex differences.

Instead of cube figures, Ruthsatz, Neuburger, Rahe, Jansen, and Quaiser-Pohl (2017) used pictures of objects that were more male (e.g., hammer, car) or female (e.g., hairbrush, doll) stereotyped with second- and fourth-grade school children. The objects used in the male version (M-MRT-3D) were more familiar to boys while the objects in the female version (F-MRT-3D) were more familiar to girls. Results of mental-rotation performance showed no significant main effects of sex or stimulus material but a significant interaction of both. The male-stereotyped nature of the male objects could lead to a higher familiarity for males while more female-stereotyped objects could be more familiar to females. The higher familiarity of participants with own-sex material could then lead to better performances.

Mental-rotation performance across adulthood

Changes in fluid and crystallized intelligence over the adult life span show decreases in fluid and increases in crystallized intelligence (Horn & Cattell, 1967) and significant declines in cognitive abilities with age (Maitland, Intrieri, Schaie & Willis, 2000). Slowing of responses seems to be one of the declines in cognitive abilities (Birren & Botwinick, 1955; Nettlebeck & Rabbitt, 1992).

As spatial abilities are assumedly fluid intelligence abilities, performance is supposed to decline with age. There are many studies (e.g., Clancy Dollinger, 1995) that confirm this assumption. Older participants reacted to and rotated objects significantly slower than younger ones (Hertzog, Vernon & Rypma, 1993; Jacewicz & Hartley, 1987; Kaltner & Jansen, 2016). For error rates, some studies showed that older participants produce more errors than younger adults (Herman & Bruce, 1983; Jansen & Heil, 2010; Puglisi & Morrell, 1986), whereas no differences between both age groups could be found in another study (Cerella, Poon & Fozard, 1981). A meta-analysis revealed large effects of age for accuracy and even larger ones for reaction time in favor of younger participants (Techentin, Voyer & Voyer, 2014).

Other studies compared the mental-rotation performance of younger and older participants with instructions to emphasize either speed or accuracy (Hertzog et al., 1993; Sharps & Gollin, 1987). Sharps and Gollin (1987) found less accurate responses in the speed condition for older participants and faster response times in the accuracy condition for younger participants. In the absence of time pressure, there are no differences in accuracy scores, but slower response times for older adults (Sharps & Gollin, 1987). In the second study, Hertzog et al. (1993) showed that older participants were less influenced by instructions than younger participants. Older participants seem to be more comfortable when they can take more time and therefore avoid making mistakes.

Trying to analyze not only the decrease with aging in cognitive ability but different representations and processes involved in mental-rotation performance, Dror, Schmitz-Williams, and Smith (2005) used complex and simple rotational objects for younger (18 years) and older (70 years) participants. Results showed an interaction of angle of rotation and complexity of the objects only for the younger group, indicating that only the younger subjects used a piecemeal rotational strategy while the older group was using a holistic strategy.

In a mental-rotation test with letters from the English alphabet as rotational objects with younger and older participants, no age differences were found for base response time and rotational speed (Jacewicz & Hartley, 1979). Using less familiar Greek letters, a significant effect of age was found, showing slower reaction times for older adults than for younger subjects. If an object is often used or seen in older adults and therefore still familiar to them, mental-rotation performance seems to be constant across adulthood.

Sex differences in mental-rotation performance of elderly participants

Jansen and Kaltner (2013) tested the mental-rotation performance of older participants with human figures and letters as rotational objects and found no sex differences in mental-rotation speed, but a higher number of correctly solved items for males than for females. Mean reaction time for all angles did not differ between males and females, but an analysis of the intercept illustrating the reaction time at an angular disparity of 0° showed a slower reaction time for females.

In a paper and pencil test with cube figures as rotational objects, the mental-rotation performance of younger and older adults showed a higher accuracy for males than for females at both age levels (Herman & Bruce, 1983).

Jansen and Heil (2010) found a significant influence of the factor sex in a paper and pencil test with polygons in three different age groups. The youngest group (23 years) showed the greatest sex difference (effect size d = 1.07); this effect was reduced by approximately half for the middle aged group (45 years) and the oldest aged (65 years) adults (Jansen & Heil, 2010).

Hypotheses

Because there are no known studies that tested elderly participants with sex-stereotyped rotational objects yet, we adopted from Ruthsatz et al. (2017) a mental-rotation test with male (M-MRT-3D) and female (F-MRT-3D) stereotyped objects and a familiarity questionnaire. Sex-stereotyped objects are items that are rated as more male stereotyped and more familiar to males (M-MRT-3D, e.g., soldier or truck) or more female stereotyped and more familiar to females (F-MRT-3D, e.g., handbag or teapot) (Ruthsatz et al., 2017).

In the current study, we examined whether higher familiarity with rotated objects was related to a better mental-rotation performance. While a male advantage in mental-rotation performance was expected, the main hypothesis was that there would be an interaction of sex and stimuli in mental-rotation performance. Female participants were expected to perform better in the F-MRT-3D than in the M-MRT-3D, and male participants were expected to perform better in the M-MRT-3D than in the F-MRT-3D. Furthermore, familiarity or the accordance of sex and stimulus type was examined as to whether they were reliable predictors of mental-rotation performance. Accordance of sex and stimulus type was either high for males who were assigned to the M-MRT-3D and females to the F-MRT-3D or low when sex and material did not match. Additionally, a negative correlation between age and mental-rotation performance was expected.

Material and methods

Participants

One hundred and seven participants (55 females and 52 males) were recruited from church meetings or retirement homes. The average age was *M* = 70.32 years (SD = 7.32) with a range from 57 to 88 years. Six participants answered a question about their highest school-leaving qualification with no qualification, 74 had low education, 19 middle, and 5 high school-leaving qualifications (no data were given by 3 participants). After informed consent was given, each participant was randomly assigned to one of the two MRT versions. Twenty-nine female and 24 male participants solved the F-MRT-3D, 26 females and 28 males the M-MRT-3D.

Material

The mental-rotation test and the familiarity questionnaire were adopted from Ruthsatz et al. (2017).

Mental-rotation tests

The two mental-rotation tests with either female- or male-stereotyped stimuli were adopted from Ruthsatz et al. (2017), which were inspired by Vandenberg and Kuse (1978). The paper and pencil tests consisted of 2 practices and 12 test items with 1 target item on the left side and 4 in-depth-rotated comparison stimuli on the right side. In both versions of the test, the same rotational angles were used (45°, 90°, 135°, 180°, 225°, 270°, 315°). Two of the comparison stimuli were identical versions of the target item; the other two were mirrored versions of the target item. Both identical items had to be crossed out. One version of the test (F-MRT-3D) consisted of female-stereotyped items (baby carriage, hairbrush, doll, ironing board, hand mirror, hairclips, handbag, dress, nail polish, hair ribbon, teapot, skipping rope; practice items: high heeled shoe and necklace), the male version (M-MRT-3D) consisted of male-stereotyped items (model airplane, hammer, corsair, cannon, saw, car, soccer goal, locomotive, revolver, truck, toy soldier, screwdriver; practice items: tractor and screw wrench) (see Figure 1). The time limit was 3 min for the 12 test items.

The mental-rotation performance was computed as the sum of all items the participant solved correctly. For each item, one point was given in case both identical stimuli were

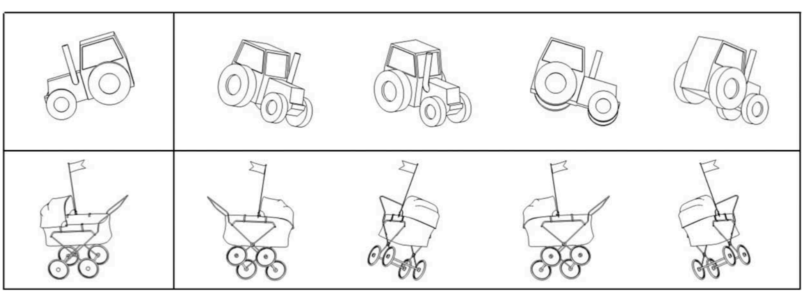

Figure 1. Example items of the M-MRT-3D (first row) and the F-MRT-3D (second row).

crossed out correctly and none of the mirrored images was. Therefore, participants could achieve a maximum score of 12 for the M-MRT-3D and the F-MRT-3D, respectively.

The test (M-MRT-3D: Cronbach's α = .840; F-MRT-3D: α = .745) proved itself as a reliable measurement (Ruthsatz et al., 2017). Ruthsatz and colleagues (2015) also examined the stereotyped nature of the objects and found that the male objects were rated as significantly male stereotyped and the female objects as significantly female stereotyped (reliability of the stereotype questionnaire: male objects: Cronbach's α = .895; female objects: α = .817).

Familiarity questionnaire

In the familiarity questionnaire, the stimuli of the F-MRT-3D and the M-MRT-3D were listed in random order with a 4-point answering scale (1 = the object is not familiar to me, 2 = the object is hardly familiar to me, 3 = the object is familiar to me, 4 = the object is very familiar to me). A familiarity score was computed by averaging the ratings of only the items the participants tried to solve.

The reliability of the questionnaire (familiarity of male objects: Cronbach's α = .860; female objects: α = .922) was confirmed by Ruthsatz et al. (2017).

Procedure

The participants were tested alone or in groups up to 10 people by 1 or 2 female experimenters. After collecting sociodemographic data about sex, age, and education, the experimenters explained the mental-rotation test and the concepts of mirrored and rotated images. Subsequently, the participants solved the practice items together with the experimenters and were able to ask questions until they understood the task. Afterward, the participants tried to solve as many test items as they could in 3 min. Thereafter, they filled out the familiarity questionnaire.

Results

Analysis of guessers

The effect of sex-stereotyped stimuli on mental-rotation performance can only be validly measured in participants who understand the mental-rotation task. Guessers were defined as participants who solved 1/6 or less of the items they attempted to solve correctly. These guessers, who performed at or below chance level, were excluded from the further analyses.

In the M-MRT-3D, 8 of 26 (30.8%) female and 7 of 28 (25.0%) male participants performed at or below chance level. The difference was not significant (χ^2 = .224, p = .636). In the F-MRT-3D, 16 of 29 (55.2%) female and 6 of 24 (25.0%) male participants turned out to be guessers, the difference was significant (χ^2 = 4.924, p = .026). More female than male participants performed at or below chance level in the F-MRT-3D.

Analyzing the age of both groups revealed no significant difference (t_{105} = −1.314; p = .191) between guessers (M = 71.59; SD = 8.41) and non-guessers (M = 69.64; SD = 6.64).

For the remaining 70 participants, the 31 females were 70.39 years old (SD = 7.91), the 39 males were 69.05 years old (SD = 5.46) with no significant difference between them ($t_{51.19}$ = .801; p = .427).

Familiarity of the stimuli

To examine whether familiarity is related to mental-rotation performance, a familiarity score should contain only the items the participants were processing. Thus, an average score of the familiarity of the items the respective subject had tried to solve was computed for each participant.

For both versions, an ANOVA showed no significant main effects of sex ($F_{1,66}$ = .002; p = .965; η^2 = .000) or stimulus material ($F_{1,66}$ = 2.707; p = .105; η^2 = .039), but a significant interaction of sex and stimulus material ($F_{1,66}$ = 7.837; p = .007; η^2 = .106) (see Figure 2).

Further analyses showed that in the M-MRT-3D, female participants had an average familiarity score of 2.53 (SD = .71) while the score of the male participants was 2.97 (SD = .68). This sex difference was significant ($F_{1,66}$ = 4.335; p = .041) with a moderate effect of η^2 = .062. Therefore, the male-stereotyped material was more familiar to male participants than to female participants. In the F-MRT-3D, female participants had an average familiarity score of 3.24 (SD = .50), the score of the male participants was 2.78 (SD = .69). This sex difference was not significant ($F_{1,66}$ = 3.596; p = .062; η^2 = .052). Hence, the female-stereotyped material was no more familiar to female participants than to male participants.

Mental-rotation performance

The examination of both versions of the MRT showed no significant main effect of sex ($F_{1,66}$ = .797; p = .375; η^2 = .012) or stimulus material ($F_{1,66}$ = .012; p = .913; η^2 = .000), but a significant interaction of sex and stimulus material ($F_{1,66}$ = 4.998; p = .029; η^2 = .070) (see Figure 3).

Further analyses revealed that in the M-MRT-3D, female participants solved 2.17 (SD = 1.47) items correctly, while male participants solved 3.38 (SD = 1.77) items. This sex difference was significant ($F_{1,66}$ = 5.587; p = .021; η^2 = .078). Thus, in the MRT with male stimuli, the male participants performed significantly better than the female participants.

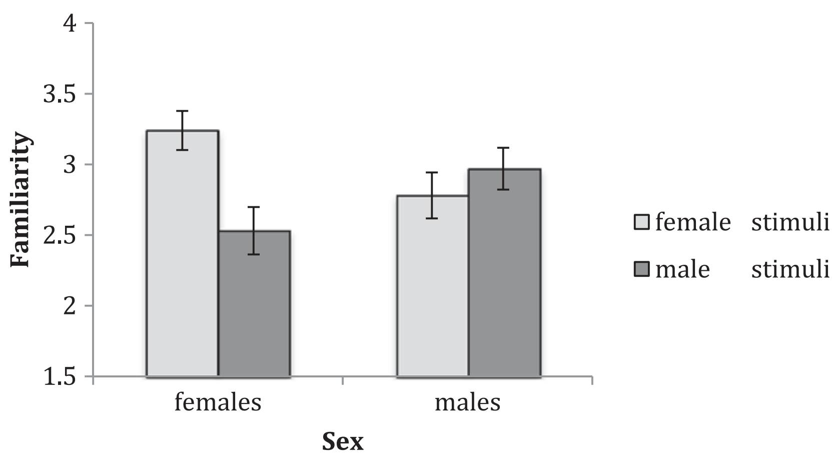

Figure 2. Familiarity as a function of sex and stimulus material. Error bars indicate SE.

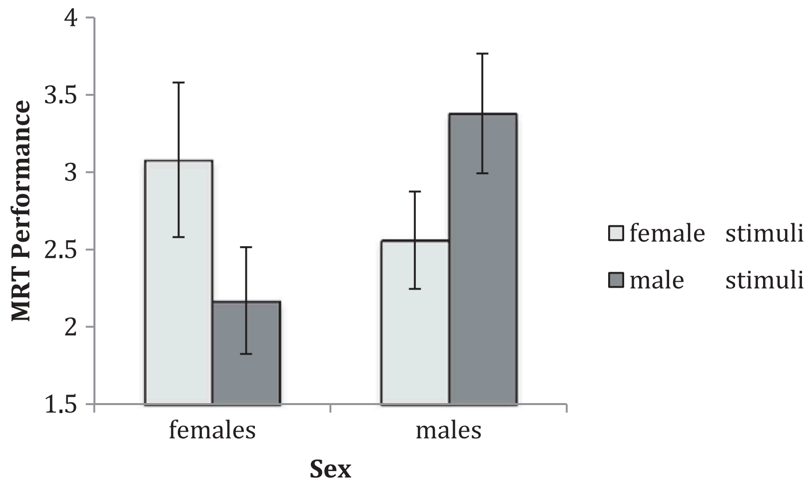

Figure 3. Mental-rotation performance as a function of sex and stimulus material. Error bars indicate SE.

In the MRT with female stimuli, female participants solved 3.08 (SD = 1.80) items correctly; the male participants had a score of 2.56 (SD = 1.34). This sex difference was not significant ($F_{1,66}$ = .802; p = .374; η^2 = .012). Therefore, no significant sex difference was found in the F-MRT.

The correlation between the mental-rotation score and the familiarity score was not significant (r = .125; p = .302).

A comparison of the participants who solved the stimulus material of their own sex (high accordance) and the participants who solved the MRT of the opposite sex material (low accordance) showed a significant difference ($F_{1,68}$ = 6.896; p = .011; η^2 = .092). Participants with high accordance solved 3.07 items (SD = .62), participants with low accordance solved 2.66 items (SD = .70).

Mental-rotation performance and age

The negative correlation between mental-rotation score and age of the participants was significant (r = −.384; p = .001) and even higher for attempted items and age (r = −.514; p < .001).

With a hierarchical linear regression, we wanted to examine the influence of age, familiarity score, and accordance on the mental-rotation performance. Accordance of sex and material was either high, in case the sex of the participants matched the stimulus material, or low in case of a mismatch. Because a significant influence of the age on the performance is confirmed by the correlation analysis, age was entered as a first step. To examine whether the familiarity score can explain additional variance to the accordance, we entered accordance as a second step and familiarity score as a third step into the regression model. All beta weights are standardized. Age (β = −.384; p = .001; 13.5% explained variance) and accordance (β = .238; p = .034; 4.4% incremental variance) were identified as reliable predictors for mental-rotation performance ($F_{2,67}$ = 8.531; p = .001; R^2 = .179). Familiarity score added no incremental explained variance and was identified as a nonsignificant predictor (β = −.007; p = .953).

General discussion

To examine whether rotational objects have any influence on mental-rotation performance and the sex differences of elderly participants, two different MRT versions were used in this study. The objects used in the F-MRT-3D were perceived as no more familiar to female than to male participants, while the objects in the male version were significantly more familiar to men than to women. These results partly replicated the results that Ruthsatz et al. (2017) found using the same material in a study with elementary-school children.

In the M-MRT-3D, male participants performed significantly better than female participants, while in the F-MRT-3D, this sex difference disappeared.

A significant interaction of sex and stimulus material was found for mental-rotation performance. The significant interaction of sex and material showed that the rotation of own-sex stimulus material seems to be easier or more successful, while in contrast the correlation between mental-rotation performance and familiarity was not significant. This contrast could be due to the fact that the participants were asked to rate the familiarity of the objects and not their estimated hands-on experience of these objects. Using an object often can mean to "have had it in one's hand" or to have rotated it manually. Using a hammer for example involves turning it around in one's hand, whereas seeing a hammer means the object is familiar but doesn't involve a manual rotation of that object. Mental and manual object rotations are often found to be similar processes with a dynamic relation between the two of them (Wexler, Kosslyn & Berthoz, 1998; Wohlschläger & Wohlschläger, 1998). The better performance with own sex objects could be due to these experiences, while a high familiarity with an object could also only signify a passive familiarity where the object is well known but not often used by the subjects themselves.

Another possible explanation could be that the own-sex material objects were perceived as less difficult without being perceived as more familiar. In this case, the mental-rotation task with these objects could lead to a better performance, as findings by Bethell-Fox and Shepard (1988) and Koriat and Norman (1985) have already suggested. If female participants perceived the male-stereotyped objects as more difficult, this would more likely lead to sex differences (Bors & Vigneau, 2011; Collins & Kimura, 1997).

Maybe the participants feel more competent with their own objects, which could lead to a higher confidence. The higher confidence should then result in a better performance (Estes & Felker, 2012).

Besides the age of the participants, the hierarchical linear regression analysis identified the accordance of sex and stimulus material as a reliable predictor of mental-rotation performance. Participants performed better when they tried to mentally rotate their own-sex material. Jansen, Quaiser-Pohl, Neuburger, and Ruthsatz (2015) found correlations between manual dexterity and rotational speed only in boys and for male items and argued that some of the male items were tools that could be used manually.

As no main effects of the stimulus material could be found for mental-rotation performance and familiarity, it seems that the female- and the male-stereotyped items are comparable in overall familiarity as well as in task characteristics such as difficulty. Furthermore, no main effects of sex could be found for mental-rotation performance and familiarity. Male and female participants rated the entirety of rotational objects as equally familiar. For the female and the male versions of the MRT (F-MRT-3D and M-MRT-3D) taken together, no sex difference was found in mental-rotation performance. Jansen and Kaltner (2013) and Herman and Bruce (1983) found a higher accuracy for males rotating letters, human figures, and cube figures in older adults; however, a study by Jansen and Heil (2010) showed decreasing sex differences with age. The absence of sex differences in this study seems to be due to the female-stereotyped rotational material since sex differences in the male-stereotyped MRT were found. Other studies found sex differences to be larger for male-stereotyped material and the performance of women in particular seems to improve with less male-stereotyped objects (Alexander & Evardone, 2008; Doyle & Voyer, 2013).

Mental-rotation performance and age

This study revealed a significant negative correlation between the number of correctly solved items and age as well as between the number of attempted items and age, which shows that mental-rotation performance declines with age. The number of attempted items can be regarded as an indicator of the speed of the processing of the cognitive task, especially since only 2 participants tried to solve all 12 items in the given time.

Several other studies found similar results when comparing younger college students and groups of older subjects (Clancy Dollinger, 1995; Herman & Bruce, 1983; Puglisi & Morrell, 1986), whereas others could not find any differences in accuracy between age groups at all (Cerella et al., 1981).

There is some evidence that older people choose to sacrifice the speed of their response time to a higher accuracy (Forstmann et al., 2011; Sharps & Gollin, 1987; Starns & Ratcliff, 2010). If they want to minimize making mistakes, older participants must take more time to make their decision. We found the negative correlation somewhat stronger for the number of attempted items and age than for the correctly solved items. The decrease in the speed of processing seems to be greater than the reduction of accuracy and my (might???) contribute to the reduction in accuracy.

Limitations

The high percentage of guessers might imply that the task was too difficult for the elderly participants. Either the participants did not understand the task or the difference between a mirrored and a rotated image was too difficult. It is conceivable that an easier test version with picture-plane rotations of the objects instead of in-depth rotations would have led to a better performance and a lower percentage of guessers. In the study with elementary school children (Ruthsatz et al., 2017), the time for the solution of the tests was 5 min while here participants had only 3 min, like in the original Vandenberg and Kuse versions for adults (1978). Maybe more time for the elderly participants would have led to more accurate results.

Studies with chronometric tests could measure the reaction time more precisely than the number of the items the participants attempted to solve. This could provide more information about the reasons of the decline.

To compare the performance of the elderly participants to younger subjects, a control group with a young aged group would be necessary. The best way to determine at what age the decline of cognitive performance in the mental-rotation abilities starts would be to test people of all age groups from 20 years on.

Conclusions

First, this study provides evidence that the material used in mental-rotation tests seems to have an influence on the performance of elderly participants (aged 57–88). Second, manipulating objects that the elderly adults are more used to seems to be less difficult for them, especially for women. Third, a decrease with age in processing speed is more pronounced than a reduction in accuracy.

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