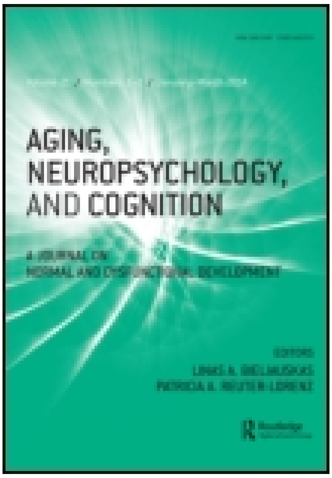


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# Object-based and egocentric mental rotation performance in older adults: The importance of gender differences and motor ability

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# Object-based and egocentric mental rotation performance in older adults: The importance of gender differences and motor ability

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## ABSTRACT

In this study, mental rotation performance was assessed in both an object-based task, human figures and letters as stimuli, and in an egocentric-based task, a human figure as a stimulus, in 60 older persons between 60 and 71 years old (30 women, 30 men). Additionally all participants completed three motor tests measuring balance and mobility. The results show that the reaction time was slower for letters than for both human figure tasks and the mental rotation speed was faster over all for egocentric mental rotation tasks. Gender differences were found in the accuracy measurement, favoring males, and were independent of stimulus type, kind of transformation, and angular disparity. Furthermore, a regression analysis showed that the accuracy rate for object-based transformations with body stimuli could be predicted by gender and balance ability. This study showed that the mental rotation performance in older adults depends on stimulus type, kind of transformation, and gender and that performance partially relates to motor ability.

***Keywords:*** Mental rotation; Motor; Performance; Gender difference; Balance ability; Older adults.

Mental rotation is the process of imagining the representation of an object when it is turned from its original position (Shepard & Metzler, 1971). In a typical object-based chronometric mental rotation task two items on a screen are presented to the participant, the right item is a rotated version of the left

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item and could be the same or a mirror version of the left item. Participants must decide if both items are the "same", not mirror reversed, or if they are "different", mirror reversed. In these kinds of studies the observer's position remains fixed and he or she has to imagine moving the object along a physical trajectory (Kosslyn, Digirolamo, Thompson, & Alpert, 1998). The objects must be judged in relation to each other, the relationship between the environment and the observer remains fixed. There are also egocentric chronometric mental rotation tasks where people have to imagine themselves rotating in order to complete the task, in this case the relationship between the environment and the object remains fixed. A typical example of an egocentric mental rotation task is the presentation of one figure type raising one arm and participants must decide which arm was raised. In this case participants are required to imagine themselves in the position of the presented figure to complete the left/right decision task (Steggemann, Engbert, & Weigelt, 2011). Zacks, Mires, Tversky, and Hazeltine (2002) separated these two kinds of transformation while using the same materials and task parameters and only varied the kind of decision: same/different vs. left/right decision. They used body figures as stimulus material. In one task, two body figures were presented simultaneously and the participant had to decide if they were same (non-mirrored) or different (mirrored-images), which gives rise to an object-based transformation. In the other task, one body figure was presented and the participant had to decide if this figure outstretched the left or right arm, which gives rise to an egocentric transformation. Reaction time, accuracy rate, and mental rotation speed are measured in chronometric mental rotation tasks.

## Mental rotation in older people

Like other various measures of cognitive functioning (e.g., Blanchard-Field & Hess, 1996), mental rotation performance declines with age; but the severity of the deficit often depends on the kind of task, object-based vs. egocentric, and the material used (Cerrella, Poon, & Fozard, 1981; Jacewicz & Hartley, 1979). Evidence for mental rotation decline with age has been found in a study with faces as stimuli. The discrimination of non-rotated faces was stable across adulthood but impaired when they were presented across different views (Habak, Wilkinsion, & Wilson, 2008). Additionally, it has been found that older adults tend to be slower and less accurate at object-based mental rotation tasks compared to younger adults (Kemps & Newson, 2005). Concerning the impact of the kind of task on mental rotation decline, Inagaki et al. (2002) compared the age-related differences between an object-based and an egocentric transformation task, which were adapted from Piaget's "Three Mountain Task" (Piaget & Inhelder, 1956). They only found an age-related decline in the egocentric perspective task but not in the object-based transformation task. However, Devlin and Wilson (2010) have shown that older adults were slower and made more errors in a mental rotation task using letters, hands stimuli, and whole-body figures. The hand and whole-body figure decision task was a left/right decision task, the letter-task a correct or mirror-reversed task. The older adults showed a decline with all stimuli, but the greatest decline in performance efficiency with whole body stimuli (Devlin & Wilson, 2010).

One explanation for the decline in an object-based mental rotation task with age is that spatial working memory is compromised (Hertzog & Rypma, 1991). Another theory is that elderly adults use a holistic strategy whereas the younger ones prefer a piecemeal rotation when meaningless stimuli are used (Dror, Schmitz-Williams, & Smith, 2005). The decline in ability to solve egocentric mental rotation tasks might be due to the difficulty to integrate information, which is related to the body schema (Devlin & Wilson, 2010). At this point it is has not yet been investigated which kind of mental rotation transformation is easier to solve for older adults when the type of stimuli is held constant.

## Gender differences in mental rotation tasks

Gender differences in mental rotation tasks are a main topic of research and widely discussed (Voyer, Voyer, & Bryden, 1995). Whereas gender differences in mental rotation tasks in studies with younger adults are widely accepted in psychometric (paper pencil) mental rotation tests, they are not as prominent in chronometric tests (Jansen-Osmann & Heil, 2007). One reason for this higher rate of gender difference in psychometric tests could be the different response format. In chronometric tests there is often a same-different decision whereas a psychometric test has a multiple choice format (Geiser, Lehmann, & Eid, 2006). In the meta-analysis of Voyer et al. (1995) 15 chronometric studies were included and seven of these showed no gender differences at all. Jansen-Osmann and Heil (2007) investigated possible gender differences in chronometric mental rotation tasks with five different stimuli (characters, primary mental ability (PMA) symbols, animal drawings, and cube figures) and a high number of participants (total $N = 360$). Polygons were the only type of stimuli, which resulted in substantial and reliable gender differences in mental rotation speed favoring males. This suggests that the male advantage in psychometric tests cannot automatically be generalized to chronometric mental rotation tasks.

To our knowledge there are only a few studies investigating gender differences in mental rotation in the elderly. In a study with 150 adults divided into three age groups (20–30, 40–50, and 60–70 years), performance decreased with age in a psychometric mental rotation task with cube figures (Mental Rotation Test; Peters, Laeng, Latham, & Jackson, 1995) and in a chronometric test with polygons as stimuli type (Jansen & Heil, 2010). In both tests of this study, accuracy rates were used as dependent measures.

Additionally, for both tests there was a reliable gender difference favoring men. However, a statistical trend toward the decline of this gender difference with age was found only in the psychometric tests. One argument against a gender difference favoring men in mental rotation is the result from the study of Pilz, Konar, Vuong, Benett, and Sekuler (2011). They showed that older males performed worse than older females (age range 60–75) at smaller angular deviations, regarding accuracy rate. Additionally, for reaction time, they found a gender difference favoring males for in-depth rotations in both younger (19–31 years) and older adults. They used a same-different matching task with amoeba-like objects, which were presented in six different angular disparities.

Along with gender differences, motor processing is another factor that can influence mental rotation performance, and both have been studied in younger adults. However, as far as we know, there is no study which investigates the relation between motor ability and mental rotation performance in older adults, even though the relationships between motor processes and cognitive processes, in general, in older adults are well investigated (Völcker-Rehage, Godde, & Staudinger, 2010).



## Motor processes in mental rotation tasks

Considerable research has investigated the relationship between motor processes and cognitive abilities, especially mental rotation ability since the work of Cooper and Shepard (1975). They used drawings of specific body stimuli (hands) and showed that participants mentally transform their own hand in the position of the drawn hand and use a comparison process. This kind of transformation was confirmed in a study from Parsons (1987) with drawings of the human body as stimuli. Twenty-three years later Wexler, Kosslyn, and Berthoz (1998) found, using an interference paradigm, that this mental rotation process was a covert motor rotation. Wohlschläger and Wohlschläger (1998) further supported this theory by showing that mental and motor rotations share common processes.

The involvement of motor processes is also shown in studies that focus on the effect of long and short-term physical activity on mental rotation performance. Studies using object-based stimuli have shown, for example, better mental rotation performance for sports and music students compared to students of education science (Pietsch & Jansen, 2012) and a positive influence of juggling training on mental rotation performance (Jansen, Titze, & Heil, 2009). In a study with preschool children it was shown that the mental rotation performance is related to motor ability (Jansen & Heil, 2010). These studies demonstrate that the relation between mental rotation and motor development is restricted to specific aspects of motor development, respectively motor control and coordinative aspects. Jansen, Lehmann, and Van Doren (2012) demonstrated that soccer-players showed a better mental rotation performance, measured by a faster reaction time, than non soccer-players in an object-based mental rotation task with body stimuli (Amorim, Isableu, & Jarraya, 2006). However, because both groups did not differ in their mental rotation speed, this group effect might be explained by differences in the encoding or motor processes while solving the task. Contrary to this positive effect for athletes when solving object-based transformation tasks, Steggemann et al. (2011, experiment 1) showed that experts for rotational movements had a better performance than non-experts only for an egocentric mental rotation task but not for object-based transformations. These contradictory results have to be investigated in more detail in further studies.

### Goal of the present study

It is the main goal of this study to investigate gender differences in older people in object-based and egocentric mental rotation while also assessing a possible influence of motor abilities and controlling the kind of stimuli. Until now, no study exists which investigates the difference in object-based and egocentric mental rotation tasks in older adults when the same stimuli type is used in both tasks. Furthermore, studies are missing which investigate gender differences in older people in object-based and egocentric mental rotation tasks while including a possible influence of motor abilities. To test motor abilities we used a test, that previously have been shown to relate to cognitive measures, the Time Up-and-Go test (Donoghue et al., 2012). The one leg stand test was used to measure balance, which has been shown to predict mental rotation ability in children (Jansen, Schmelter, Kasten, & Heil, 2011).

## METHODS

### Participants

Sixty adults between 60 and 74 years old participated in the study. There were 30 men (mean age: 66.03, $SD = 4.11$) and 30 women (mean age: 66.23, $SD = 3.47$). Participants were recruited through advertisements in the local newspapers. All participants received €10 for participation. None of the adults showed a cognitive deficit, as measured with the Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975) and the Clock Test (Tuokko, Hadjistavropoulos, Miller, & Beattie, 1992), see Table 1. All participants gave informed consent for participation.

### Apparatus and Stimuli

#### *MMSE and Clock-Test*

The MMSE consisted of 30 questions concerning everyday knowledge, memory performance, etc. Participants, who answered less than 26 questions

**TABLE 1.** Age, MMSE, Clock test, OLS, CST, TUG dependent on gender (Mean, *SD*)

| | Male | Female |
|---|---|---|
| Age | 66.23 (3.47) | 66.03 (4.11) |
| MMSE | 28.46 (1.20) | 28.83 (0.98) |
| Clock test | 7.00 (0) | 6.86 (0.51) |
| One leg stand (OLS) | 50.53 (17.8) | 47.88 (20.10) |
| Chair stand test (CST) | 20.11 (5.59) | 21.45 (5.04) |
| Time up-and-go test (TUG) | 6.25 (1.91) | 6.44 (2.38) |



correctly, were excluded. The range of correct answers varied between 27 and 30. The Clock Test had a total of 7 possible points. All participants who had less than 5 points were excluded. In this test there was a range from 5 to 7 points.

### *Mental rotation test*

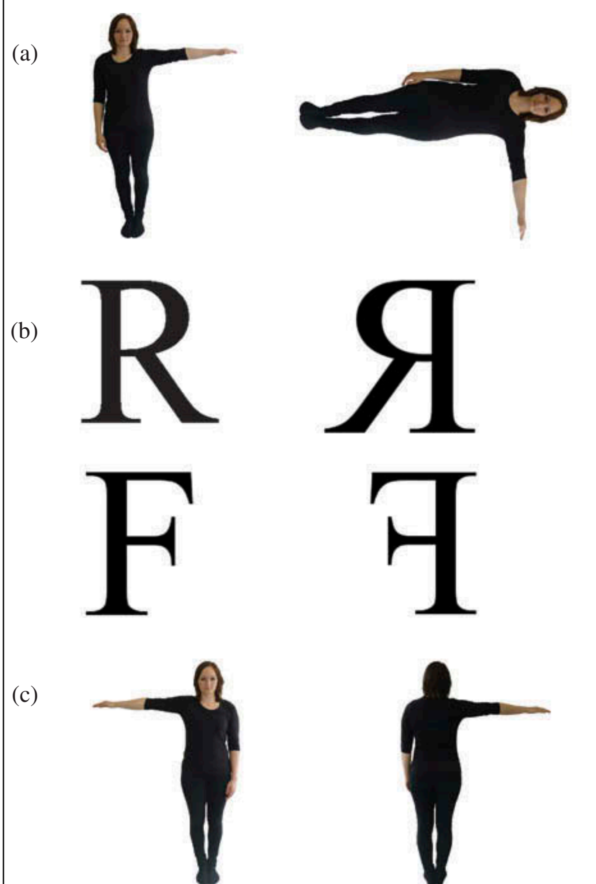
For the mental rotation task, the experiment was run on a laptop with a 17″ monitor located approximately 60 cm in front of the participant. Adapted from the work of Steggemann et al. (2011) the experimental stimuli consisted of three different stimulus types: (a) frontal view of two female people with either the left or the right arm extended (body figure object based: BFO), (b) the letters R and F, and (c) front and back view of one female person with either the left or right arm extended (body figure egocentric: BFE), see Figure 1.

Two drawings of the same kind of stimuli were presented simultaneously in the letter and BFO condition. For each stimulus type the two stimuli were presented pairwise with an angular disparity of 0°, 45°, 90°, 135°, or 180°, in which the right stimuli was obtained by the rotation of left stimuli, the so-called "comparison figure". Half of the trials were pairs of identical objects and half were mirror-reversed images. The letters were black and the human figures were wearing black clothes. In the BFE condition only one figure was presented in the rotation angles mentioned above. This figure raised either the left or right arm. All stimuli were rotated in the picture plane.

### *Motor tests*

1. One leg stand (OLS; Vellas, Wayne, & Romero, 1997): This test measured the ability to stand on one leg as long as possible (maximum 60 seconds). Participants had to raise the leg of their choice with the foot approximately six inches off the ground, keeping the

**FIGURE 1.** Examples of the three different stimuli types: (a) body figures object based (BFO), (b) letters, and (c) body figures egocentric (BFE). The images are similar to those used in the mental rotation task of this study.




raised foot parallel to the ground, while holding their arms still at their sides. The time standing on one leg was measured in seconds.

2. Chair stand test (CST; Csuka & McCarty, 1985): This test measured leg strength and endurance. Participants sat on a chair as far back as possible in the seat. They were asked to stand up and sit down 10 times, always returning completely to the correct starting position. They had to stand up and sit back down as quickly and as safely as possible. The experimenter measured the time in seconds they needed to complete this task.
3. Timed up and go test (TUG; Podsiadlo & Richardson, 1991): The timed up and go test is a test of mobility. It measured the time taken

by a participant to stand up from a standard chair, walk a distance of 3 meters, turn around, walk back to the chair and sit down. The time needed to complete the task was measured in seconds.

## Procedure

The individual test sessions, which lasted about 60 minutes in total, took place in a laboratory at the University of Regensburg. At the beginning of the session each participant completed the MMSE (Folstein et al., 1975) and the Clock Test (Tuokko et al., 1992), followed by the motor tests.

Afterwards, the mental rotation test was conducted. Task instructions were standardized. In the BFO and letter conditions participants had to decide as quickly and as accurately as possible if the stimuli were either the same or different, which means whether or not the stimulus on the right side was identical to the comparison stimulus (showed on the left side). Participants had to press the left mouse button (left-click) when the two stimuli were "same" and the right mouse button (right-click) when the two stimuli were "different". When the stimuli from the BFE condition were presented, participants had to decide if the figure had the right or the left arm raised. In this condition participants had to press the left mouse button (left-click) when the figure raised the left arm and the right mouse button (right-click) when the right arm was raised.

Each trial began with a fixation cross for 1 second. After that, the pair of stimuli appeared and stayed on the screen until participants answered. Feedback was given for 500 ms after each trial: in the case of a correct response a "+" appeared in the centre of the screen and in the case of an incorrect response a "–" appeared. The next trial began after 1500 ms. Each type of stimulus was presented in a separated block which was preceded by eight practice trials. There were 80 trials in each of the three blocks (without counting the practice trials). After every 10 trials within each block a pause of 15 seconds was given before the next 10 trials were administered. The next block started after a break of around one minute. The presentation of the three blocks was randomized.

Each participant performed 3 blocks of 80 experimental trials, resulting in 240 trials: 3 stimulus types (BFE vs. BFO vs. objects) $\times$ 2 trial types (same vs. different) $\times$ 5 angular disparities (0°, 45°, 90°, 135°, or 180°) $\times$ 4 repetitions of each combination. In each block the order of the presentation of the stimuli was randomized.

## Statistical analysis

First, three different univariate analyses of variance were conducted with "performance in the motor test" as the dependent variable and the factor "gender" as the independent variable. Second, regarding the mental rotation test, two repeated measure analyses of variance were conducted with "stimulus type", "gender", and "angular disparity" as factors and "reaction time" (RT) and "accuracy rate" as dependent measurements. Furthermore, an analysis of variance was calculated with "mental rotation speed" as a dependent measurement and "stimulus type" and "gender" as independent measurements. Mental rotation speed was calculated as the inverse of the slope of the regression line, calculated separately for each subject, relating RT to angular disparity and was expressed as degrees per second. Data of five people (four men, 63, 59, 70, and 71 years old and one women, 74 years old) had to be excluded because rotation speed was negative (2) or was higher than 3 standard deviations above the mean of the specific stimuli. Fourth, one analysis of variance was calculated with "reaction time at 0°" as the dependent measurement and "stimulus type" and "gender" as independent measurements. The RT at 0° corresponds to the intercept of the reaction time function. The intercept of the reaction time function reflects the perceptual comparison stages, and the decision processes in the mental rotation process.

Because there was only a gender difference seen for accuracy rate and motor performance, a correlation and regression analysis were conducted between the performance in the motor task and the accuracy rate (only for the rotated items).

## RESULTS

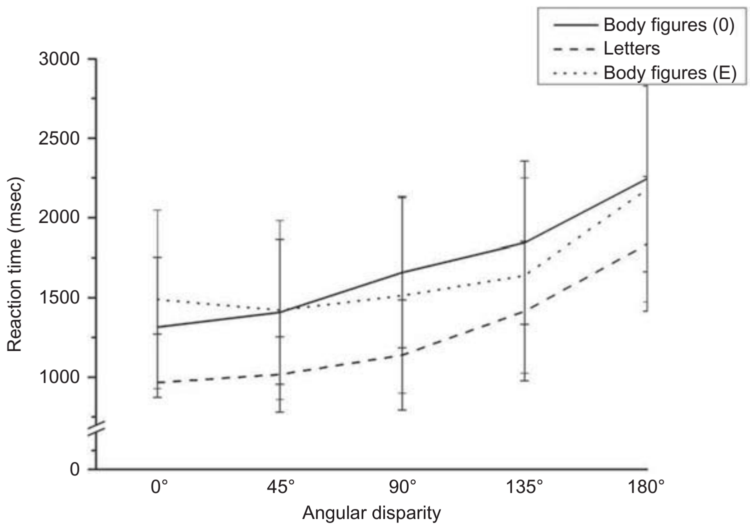
### Motor tests

There were no gender differences for all three dependent motor measurements, the OLS, $F(1, 58) = .29$, *ns*, the CST, $F(1, 58) = .95$, *ns* and the TUG, $F(1, 58) = .11$, *ns* (see Table 1).

### Mental rotation: Reaction time (RT)

Concerning reaction time, the analysis of variance showed a main effect for the factors "stimulus type", $F(2, 116) = 21.09$, $p < .001$, $\eta^2 = .26$, and "angular disparity", $F(4, 232) = 296.93$, $p < .001$, $\eta^2 = .83$, and a significant interaction between both factors, $F(8, 464) = 7.18$, $p < .001$, $\eta^2 = .110$ (see Figure 2). Figure 2 shows that the reaction time for letters was lower than that for the human figures conditions. For the BFO and letters condition the reaction time was higher for each consecutive angle (all contrasts $p \leq .05$). For the BFE condition the reaction time for 45° was not higher than for 0°, $F(1, 59) = 3.64$, *ns,* and the RT for 90° did not differ from that of 45°, $F(1, 59) = 2.17$, *ns*. All other contrasts in this condition were significant, $p < .05$. There was neither a main effect of gender, $F(1, 58) = 3.28$ nor any significant interaction with the factor gender. The family-wise alpha error was below 5% for each tested hypothesis.

**FIGURE 2.** Reaction time dependent on stimuli type and angular disparity.



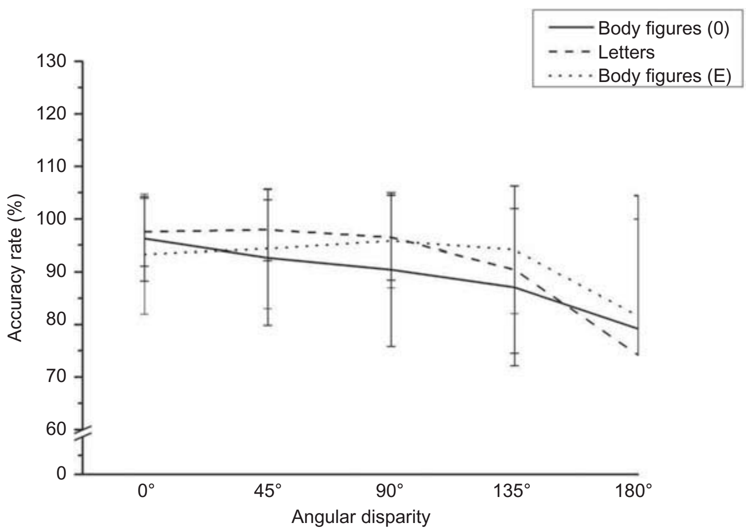



## Mental rotation: Accuracy

Concerning accuracy, the analysis of variance showed a main effect for the factor “angular disparity”, $F(4, 232) = 58.678$, $p < .001$, $\eta^2 = .50$, and a significant interaction between the factors “angular disparity” and “stimulus type”, $F(8, 464) = 3.37$, $p < .001$, $\eta^2 = .06$ (see Figure 3). Figure 3 shows that for the BFO condition the accuracy rate was higher for each consecutive angle (all contrasts $p \leq .05$). For the letter and the BFE condition the accuracy rate for 45° degree was not higher than for 0°: $F(1, 59) = 1.31$, *ns*, and $F(1, 59) = .71$, *ns*; the accuracy rate for 90° did not differ from that of 45°: $F(1, 59) = 1.87$, *ns*, and $F(1, 59) = 3.30$, *ns*. Furthermore in the BFE condition the accuracy rate did not differ between the angular disparities of 90° and 135°. All other contrasts in both conditions did differ ($p < .05$). There was also a main effect of “gender”, $F(1, 58) = 4.67$, $p < .05$, $\eta^2 = .075$, but no significant interaction with the factor “gender”. Males ($M = 93.33\%$, $SD = 4.74$) solved more items correctly than females ($M = 88.19\%$, $SD = 8.52$). Differentiating between the accuracy rate in the 0° condition, $F(1, 58) = 7.98$, $p < .01$, $\eta^2 = .12$, and in the mean of the rotated conditions, $F(1, 58) = 8.31$, $p < .001$, $\eta^2 = .13$, both analyses showed significant gender effects favoring males.

Further analysis showed that the mean reaction time was negatively correlated with the accuracy rate ($r = -.615$, $p < .01$). This holds true for both males ($r = -.483$, $p < .01$) and females ($r = -.672$, $p < .01$).

FIGURE 3. Accuracy rate dependent on stimuli type and angular disparity.





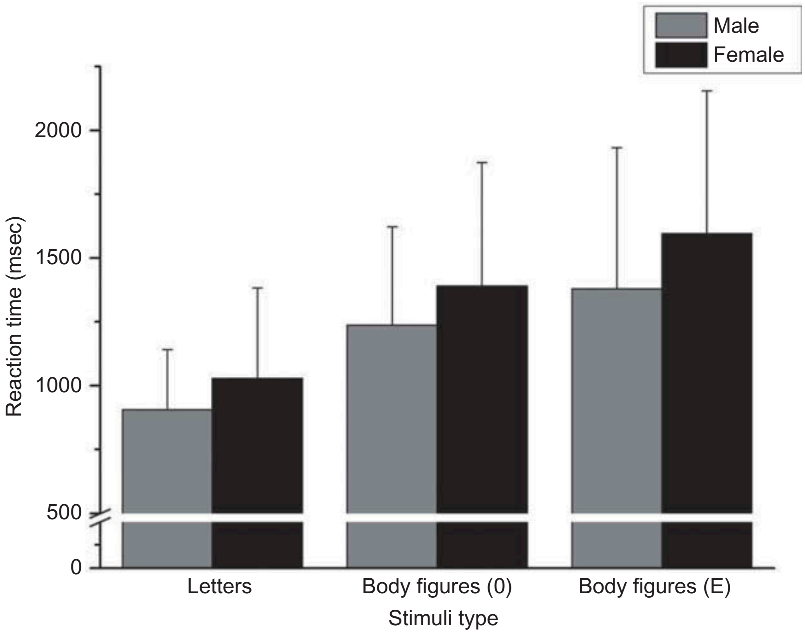

## Mental rotation speed

The univariate analysis of variance showed a significant main effect for the factor "stimuli type", $F(2, 106) = 9.915$, $p < .001$, $\eta^2 = .158$, but no significant main effect for the factor "gender", $F(1, 53) = 1.38$, *ns,* and no interaction between both factors, $F(2, 106) = 1.3$, *ns.* Contrasts revealed that the rotation speed in the BFE condition ($M = 388.46°/\text{s}$, $SD = 325.14$) was higher than in the BFO ($M = 245.85°/\text{s}$, $SD = 174.89$), $F(1, 53) = 12.18$ $p = .001$, $\eta^2 = .187$ and letter condition ($M = 248.15°/\text{s}$, $SD = 133.89$), $F(1, 53) = 9.35$, $p < .01$, $\eta^2 = .150$. The last two conditions did not differ from each other, $F(1, 53) = .788$, *ns.*

## Intercept

Analyzing the reaction time at an angular disparity of 0°, the univariate analysis of variance showed a main effect of "stimulus type", $F(2, 116) = 26.01$, $p < .001$, $\eta^2 = .31$, and an effect of "gender", $F(1, 58) = 4.62$, $p < .05$, $\eta^2 = .07$ but no significant interaction between these factors, $F(2, 116) = .215$, *ns*, see Figure 4. Females ($M = 1338.61$ ms, $SD = 318.54$) show a slower reaction time than males ($M = 1173.81$ ms, $SD = 273.45$). Furthermore, the reaction time was faster for letters ($M = 966.71$ ms, $SD = 304.81$) than for the BFO ($M = 1313.43$ ms, $SD = 440.63$), $F(1, 59) = 36.8$, $p < .001$, $\eta^2 = .38$, and BFE figures ($M = 1488.03$ ms; $SD = 560.56$), $F(1, 59) = 54.61$, $p < .001$, $\eta^2 = .48$, but there was only a tendency

**FIGURE 4.** Reaction time at 0°, dependent on stimuli type and gender.






of significance between the two human figures conditions, $F(1, 59) = 3.89$, $p = .053$, $\eta^2 = .06$.

Because the age range was very wide, the analyses presented above were conducted again by integrating a new factor, age group, in which the participants were split into two groups according to their median (66 years). The additional analyses concerning reaction time at both rotated items and at an angular disparity of 0°, error rate, mental rotation speed and reaction time only revealed a difference between age groups for error rate. Young adults ($M = 7.54\%$, $SD = 5.96$) made fewer errors than old adults ($M = 11.03\%$, $SD = 8.16$). There were no other main effects or significant interactions among the factor of age group or any other dependent measures.

## Correlation and regression: Accuracy rate and motor performance

Accuracy rates for the rotated items were averaged. All motor tests correlated with the mental rotation accuracy rate, OLS ($r = .334$, $p < .05$), CST ($r = -.279$, $p < .05$), and TUG ($r = -.272$, $p < .05$). There were no correlations between the motor tests and the reaction time for the rotated items and the mental rotation speed. A correlation analysis separated for the three different stimuli types showed that only OLS ($r = .365$, $p < .05$) and TUG ($r = -.315$, $p < .05$), correlate significantly with the accuracy rate only in the

**TABLE 2.** Final stepwise multiple regression model for the mental rotation performance in the BFO task (accuracy rate) based on the following predictors: gender, one leg stand, chair stand test and timed up-and-go test

| Predictor | Regression coefficient | $\beta$ | $t$ | $p$ |
|---|---|---|---|---|
| Gender | −6.353 | −0.275 | −2.329 | <.001 |
| One leg stand | .213 | 0.346 | 2.925 | <.01 |
| Chair stand test | | −0.061 | −0.500 | >.05 |
| Timed up-and-go test | | −0.174 | −1.923 | >.05 |

BFO task. No other correlation was significant. A stepwise regression analysis showed that gender and one leg stand explained 22.8% of the variance in the accuracy rate in the BFO task ($R = .470$), $F(2, 57) = 8.09$, $p = .001$, see Table 2.

## DISCUSSION

Our results show that the performance of older people on a mental rotation task depends on the kind of mental rotation task, whether it is an object-based or an egocentric mental rotation task. Furthermore, gender differences exist in the accuracy rate of the mental rotation task independent of the kind of task and the performance could be predicted by gender and balance ability.

### Mental rotation in older adults in an egocentric and object-based mental rotation task

Analyzing reaction time, the results show that the performance of the older people in a mental rotation task differs with respect to the kind of task. Comparing only the results within the same type of stimuli, human figures, our results show that the egocentric presented human figure was easier to process for older people than the object-based human figures. In a study with younger participants and body drawings as stimuli, Zacks et al. (2002) found a linear relationship between mental rotation time and angular disparity in a same-different performance but no relationship between mental rotation time and angular disparity in left-right mental rotation performance. The result of the present study regarding the object-based transformation is in line with results of the study of Zacks et al. (2002). However, the present study differs from Zacks et al. (2002) in the egocentric mental rotation task results for the more difficult tasks, because we found a linear relationship between reaction time and angular rotation of 135° and 180°. Those body rotations are not physically attainable in normal life. This suggests that the difficulty of the tasks plays an important role for older adults while solving egocentric mental rotation tasks. Evidence for this assumption comes from a study of Saimpont, Pozzo, and Papxanthis (2009). In their study, 20 young and

19 older participants had to judge the laterality of hand stimuli, which were presented in different orientations. They showed that the slowing of the reaction time dependent on angular disparity was significantly higher for older participants.

These results provide further support for the dissociation of the processing of object-based and egocentric transformation tasks, at least for less difficult tasks, suggested by neurophysiological data (Zacks, Rypma, Gabrieli, Tversky, & Glover, 1999 for a review). For less difficult tasks, our results are also in line with the hypothesized transformations. Object-based mental rotation tasks are isomorphic to the physical movement of the object (e.g., Kosslyn, 1994). The egocentric mental rotation task requires the participant to imagine themselves in the position of the rotating figures; for this type of rotation it was shown that the effect of increasing reaction time with increasing angular disparity was attenuated (Presson, 1980). Quite interestingly, and in contrast to the study of Steggemann et al. (2011), elderly people were faster in the object-based mental rotation task to solve letters than body figures. One might assume that the letter is very familiar to the older people and because of this easier to process, whereas the human figure is recognized as a young women, which is also familiar but not as familiar as the presented letter. The familiarity of the letters might have activated the cognitive representation of the object as a unit. If so, this induced the use of a holistic strategy (e.g., Bethell-Fox & Shepard, 1988) for some types of meaningful stimuli (e.g., letters). The presented study adds to the results of Dror et al. (2005) who investigated older peoples' use of a holistic strategy while solving mental rotation tasks with meaningless stimuli. The results of the presented study could not be directly compared with those of Devlin and Wilson (2010), because they were more interested in age decline and did not compare the results within the different stimuli types for the older age group.

Concerning accuracy rate, the object-based mental rotation task with human figures showed a linear decrease with rotation angle, this was not the case in the letters task or the egocentric mental rotation task with the human figures. There was no linear increase concerning error rates up to 90° for letters or up to 135° in the BFE task. The same pattern of results was seen with young adults in an object-based transformation task with letters (Steggemann et al., 2011). Non-motor experts did not show a linear increase in the error rate for letters up to an angular disparity of 90° (Figure 3, Steggemann et al., 2011). Our results give a hint that both tasks were relatively easy for the elderly participants to process. Further analysis showed that there was no speed-accuracy trade off, because reaction time correlated negatively with the accuracy rate. This holds true for males and females. Participants who answered faster also had a higher accuracy rate. The different result patterns for speed and accuracy may not be due to a different strategy (accuracy vs.

speed) used by males and females, but rather different internal processing (holistic vs. piecemeal) (Amorim et al., 2006).

## Gender differences in object-based and egocentric mental rotation tasks

Our results show gender differences in mental rotation tasks independent of the type of stimuli. These gender differences appeared in the accuracy score as well as in the intercept of the mental rotation speed, but not in the mental rotation speed itself or the overall reaction time for the rotated items. At first glance this gender difference is in line with the study of Jansen and Heil (2010) who found a gender difference in accuracy rate for older people for all angles besides 0°, where a rotation is not necessary. The present study did find a gender difference in the 0° condition for both reaction time and accuracy rate. This allows us to assume that the gender difference might be due to a difference in other cognitive domains and not the mental rotation process itself, at least when human figures and letters are used as stimuli types. An aspect indicating this is the result that females have a slower reaction time for the non-rotated items than males, suggesting that the gender difference may lie in the perceptual or decision processes. Evidence for this assumption comes from a study of Mikhailova, Slvutskaya, and Gersimenk (2012). They showed in an EEG experiment that only males were affected in the early perceptual stage of transformation by one previously learned object. Furthermore, Semrud-Clikemann, Fine, Bledsoe, and Zhu (2012) showed that males had a higher activation than females in brain networks which are involved in visual attention while solving a mental rotation task. Both neuropsychological studies show a gender difference in perceptual processes, which suggests that gender differences in a mental rotation task might be attributable to perceptual processes and not the rotation process itself. The existence of general cognitive gender differences in late adulthood is widely discussed and varies depending upon methodology and measures employed (compare Maitland, Intrieri, Schaie, & Willis, 2000; Parsons, Rizzo, Zaag, McGee, & Buckwalter, 2005).

The results of this study suggest that if gender differences exist in mental rotation in older adults they seem not to be dependent on whether the transformation is object-based or egocentric. This is a fairly novel result, because until now gender differences in older adults favoring males were found with cube figures (Jansen & Heil, 2010) and favoring females with amoeba-like objects in the accuracy rate (Pilz et al., 2011). Further studies must be conducted which investigate gender differences in mental rotation with different types of stimuli in object-based and egocentric transformation tasks in late adulthood; more information is needed to make conclusive remarks regarding gender differences in mental rotation in that age range. Until now this was only investigated with young adults (Jansen-Osmann & Heil, 2007) and with school-aged children (Jansen, Schmelter, Quaiser-Pohl, Neuburger, & Heil, 2013), and only using object-based transformations. There are two prominent explanation strategies for the gender differences in mental rotation, biological and sociological. On the one hand, concerning the biological theory, it was proposed that the sex steroid hormones, testosterone and estradiol, influence mental rotation performance (Hausmann, Slabbekorn, van Goozen, Cohen-Kettenis, & Güntürkün, 2001). On the other hand, there exists evidence for a socio-cultural explanation, which argues that domain-specific self-concept of ability influences achievement (e.g., Marsh & Craven, 2006). The influence of hormone and self-concept in older persons while solving a mental rotation task has not yet been investigated.

## Motor processes in mental rotation tasks

The results of this study, which did not show any gender differences in the motor tasks, did show a correlation between the overall mental rotation performance and motor task performance. In a second analysis it was shown that only the mental rotation performance in body figure object-based task correlates with the OLS and TUG. A regression analysis revealed that the mental rotation performance measured by accuracy rate in the BFO task could be predicted by gender and balance ability. This is a quite interesting result because it agrees with the result of the study of Jansen and Heil (2010) who showed that coordinative ability predicted mental rotation performance in preschoolers. Furthermore, Jansen et al. (2010) found that overweight children with poor motor performance also showed poor mental rotation performance, and that balance ability could predict poor performance among these children. This could also be seen in line with a result of Schäfer, Krampe, Lindenberger, and Baltes (2008). They demonstrated in a dual-task study that adults showed performance deficits in a balance and working memory task compared to adolescents. This could be explained by the fact that keeping postural stability requires more cognitive resources in late adulthood than in adolescence. Higher demand on cognitive resources may be due to decline in visual acuity, muscle strength, and joint flexibility (Schäfer & Schumacher, 2011).

At first glance one might wonder why the relation between balance and mental rotation could be only detected for the object-based tasks with human stimuli but not for the egocentric tasks. Since the mental rotation speed was fastest for the egocentric body stimuli, this result could not be explained by lack of difficulty of the task. One crucial point might be that balance performance relies on visual acuity, which is also a relevant factor for the comparison of two objects in a same/different task. Additionally, letters were presented in a same/different task and they were less demanding concerning their visual acuity demands than the body figures stimuli. According to these results it might be very interesting to investigate the influence of visual acuity in more detail. In this case, the influence of the visual system while performing a balance task and the visual quality of the stimuli presentation could be varied. Moreover, it could be investigated if balance training improves mental rotation performance, especially with BFO stimuli. Evidence for the effectiveness of juggling training on mental rotation performance was already demonstrated (Jansen et al., 2009). In a new study the question of gender differences must be integrated into the design.

Another crucial point is that the relation between object-based transformation and motor ability was only seen in the accuracy rate but not in reaction time or mental rotation speed, which is in line with a study with healthy and overweight children (Jansen et al., 2011). Because the accuracy rate measurement is also sensitive to working memory effects (Amorim et al., 2006) the question arises if the motor performance would correlate with visual-spatial memory tests. Evidence comes from a study showing that age-related decline in visuospatial working memory correlates with the decline in a finger movement sequence-learning task (Bo, Borza, & Seidler, 2009). Furthermore, Anguera, Reuter-Lorenz, Willingham, and Seidler (2011) showed that older adults were not able to use spatial working memory components in the initial learning phase of a visuomotor adaptation task.

## LIMITATIONS

This study may be limited by the specific spatial and motor measures that were utilized. Mental rotation is only one of the visual-spatial abilities, and perhaps more should be included. The motor tests only measure balance, mobility, and strength but not more coordinative abilities or endurance. These tests were chosen based on the results of the studies with younger participants and had to be expanded to other aspects of motor and visual-spatial ability, for example visualization and orientation (Linn & Peterson, 1985). Inclusion of additional tests could provide a better insight to the relationship between cognition and motor ability. Additionally, as in the study of Völcker-Rehage et al. (2010), the influence of physical fitness in addition to motor performance could have been included to measure the effect on mental rotation performance in older adults.

This study is also limited by the fact that only older adults were investigated. It would be interesting to repeat this study with younger adults and compare the results of the two age groups. No such study exists at the moment, and it would help to clarify whether the partial relationship between motor and mental rotation performance is reduced or enhanced in older age. Until now, quasi-experimental and experimental studies exist showing an influence of long-term (Moreau, Clerc, Mansy-Dannay, & Guerrin, 2012) and short-term coordinative training (Jansen et al., 2009) on mental rotation performance in young adults, but this has not been investigated throughout the lifespan.

## CONCLUSION

This study showed the existence of gender differences in egocentric and object-based mental rotation tasks for accuracy measures obtained in older adults. Furthermore, visual-spatial performance could be predicted by both balance ability and gender. This study is limited by the fact that the underlying causes for the results could not be revealed. There are many questions remaining for future research: Do testosterone and estradiol correlate with mental rotation performance? Does stereotype threat, which refers to a negative stereotype of the own groups and which becomes relevant for oneself, have an influence on mental rotation performance in the elderly? Moreover, more motor tests could be applied and working memory capacity could be analyzed. As mentioned in the introduction, the application of a holistic vs. an analytic strategy could be investigated. However, first a systematic examination of gender differences in adulthood, using different experimental tasks and stimuli types, is necessary.

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