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Research Article

Mental body rotation with egocentric and object-based transformations in different postures: standing vs. balancing

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HIGHLIGHTS
- Performance is better for egocentric than for object-based transformation.
- Posture has no influence on the performance in a mental body-rotation task.
- An egocentric transformation leads to more postural stability than an object-based one.
- Mental and no-mental-rotation tasks generate same postural sway parameters.

ABBREVIATIONS

ANOVAs	Analyses of variance
AP	Anterior-posterior
CoP	Center of Pressure
MBRT	Mental body-rotation task
ML	Medial-lateral
MRT	Mental rotation task
RE	Response error
RT	Response time

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BACKGROUND: Previous studies suggest better visual-spatial processing when participants are tested in postures in which dynamic stability is challenged. The question arises if this is also true for the performance in mental body-rotation tasks (MBRT).
AIM: Taking the embodied cognition approach into account, the first aim of the present study was to examine the potential influence of different demands on dynamic stability for two postures (parallel stand vs. tandem stand) on solving two versions of the MBRT, inducing either an object-based or an egocentric perspective transformation strategy. The second aim was to investigate if these different demands on dynamic stability are reflected in postural sway parameters.
METHOD: Thirty participants (18 females and 12 males) were tested in the two MBRTs and in a control condition. All tasks were performed while standing on a balance beam in tandem stand and in a feet parallel position on a force plate.
RESULTS: The results for response time and response error revealed effects of rotation angle and task, but no effect of posture. The analyzed Center of Pressure (CoP) data revealed a reduction of body sway during the MBRT for egocentric perspective transformations.
CONCLUSION: The results indicate that participants performed better for egocentric than for object-based transformations and that the egocentric transformation leads to more postural stability than the object-based.

KEYWORDS: Mental body-rotation | Postural control | Embodied cognition

INTRODUCTION

Mental Rotation is the "ability to spatially transform two-dimensional or three-dimensional objects or bodies from one orientation in mental space to another".[1] In the classic chronometric mental rotation task (MRT), Shepard and Metzler[2] presented two three-dimensional objects (i.e., cube figures) in different orientations and found a linear relationship between angular disparity and reaction time, with steadily increasing reaction times for larger angular disparities. Subsequently, this pattern of results has been replicated and generalized to a variety of different stimuli, like for example two-dimensional shapes,[3] letters,[4,5] images of human body parts,[6] or whole human bodies.[4,7,8,9,10] The present study investigates the visual-spatial transformation of human bodies, which is an extension of the standard MRT by Shepard and Metzler[2] and involves the mental rotation of whole-body figures. It has been therefore termed mental body-rotation task (MBRT).[11]

For the mental rotation of human bodies, there are two types of transformations, which represent different cognitive strategies.[12] For object-based transformations, the observer´s position remains fixed and an object is mentally rotated relative to a reference frame in the environment. For example, when presenting two human figures side-by-side in different orientations, one object serves as the reference frame while the other object is spatially transformed and compared to this reference frame, typically in a same-different judgment.[9,10] In contrast, egocentric perspective transformations are imagined rotations of the observer's point of view relative to a reference frame while the position between the object and the environment remains fixed. For example, when displaying a single human figure with the left or right arm stretched out in different orientations, the observer uses his/her own body as a reference and "puts himself/herself into the object" for the mental rotation, typically for a left-right judgment. According to Stins and colleagues,[13] egocentric transformations are based predominantly on kinaesthetic imagery, where a person imagines performing a movement himself/herself, while object-based transformations rely stronger on visual imagery, where a person imagines someone else performing a movement. This is also supported by neural findings showing that object-based transformations rely on object-centered representations, whereas egocentric transformations rely on simulated body movements.[14] Which kind of strategy is used for a particular spatial transformation thus depends on the task that has to be solved: An object-based transformation strategy is used when participants perform a same-different judgement, while an egocentric perspective transformation strategy is evoked by the single human figure when the task requires a left-right judgment.[12]

The present study investigates if performance in MBRTs is influenced by different postural control demands when people take up postures, which challenge dynamic stability (i.e., when standing on a balance beam in a tandem stand vs. in a parallel stand on even ground). Such an influence can be predicted based on previous studies investigating different perceptual-cognitive tasks. For example, Bray and colleagues[15] found better performance in a visual judgment task when participants were standing in a tandem stand on a balancing beam (compared to standing in a parallel stand or sitting on a chair). These results suggest that visual-spatial processing improves when postural control is (more or less) challenged, requiring higher efforts to maintain dynamic stability. It is therefore of interest if this is also true for the performance in a mental body-rotation task, because to our knowledge participants have been usually tested in mental rotation tasks while sitting[5,9,10] and thus, postural control and dynamic stability were not challenged to great degree.

A strong link between postural control processes and mental processes is predicted in the theoretical framework of embodied cognition, which assumes that mental processes also have a motor component and thus both processes cannot be separated from each other.[16,17] Based on this framework, Budde et al.[18] recently tested participants in two different postures, either sitting or standing, in the MBRT requiring either an object-based transformation (i.e., same-different judgment) or an egocentric perspective transformation (i.e., left-right judgment). Like in other studies examining the mental rotation of human bodies,[8,9,10,11] response times were faster and more accurate for egocentric perspective transformations than for object-based transformations. However, there was no effect of the posture in which participants performed, sitting on a chair vs. standing in a parallel stand, respectively. The authors presented two arguments for why posture may not have affected performance in the two versions of the MBRT. First, the challenge to dynamic stability may not have been big enough when participants were standing in a parallel stand. In line with this first argument, Kawasaki and colleagues[19] found a correlation between the performance in a MRT and postural sway parameters (total length of sway, sway velocity in anterior-posterior and medial-lateral direction, root mean square), but only when foot stimuli where used (and not cars) and when participants stood on one foot (i.e., for unipedal, but not bipedal stands). Second, response time and error rate data may not be sensitive enough to reveal an effect of different postures on mental rotation.[18] In line with this second argument, Dault and colleagues[20] revealed an increase in the frequency and a decrease in the amplitude of postural sway when participants solved a MBRT (using stickman figures as stimuli), in contrast to a control condition (simply fixating on a point at the computer screen). Similarly, Hofmann and Jansen[21] also observed effects of postural stabilization during the mental rotation of human bodies as compared to a control condition (looking at a fixation cross).

The present study

Following the prior study by Budde and colleagues[18] and taking the results of the previous studies[19,20,21] and the embodied cognition framework[16,17] into consideration, the present study further investigates the link between postural control and mental body-rotation. To the best of our knowledge, besides our own previous study, there have only been two studies examining the relationship between postural control and mental rotation, one with "real" human bodies[21] as stimuli and one with stickman[20] as stimuli. Therefore, more research on this topic is warranted. The first aim is to examine the potential influence of different demands on dynamic stability for two postures (parallel stand vs. tandem stand) on solving two versions of the MBRT, inducing either an object-based transformation strategy for same-different judgments (i.e., when two human figures are presented side-by-side in different orientations) or an egocentric perspective transformation strategy for left-right judgments (i.e., when a single human figure is presented with the left or right arm stretched out in different orientations). With regards, two predictions are made: Based on previous studies,[9,10,11,18,23] it is expected that participants perform better in the MBRT (as signified by faster response times and fewer error rates), when using an egocentric perspective transformation strategy, as compared to an object-based transformation strategy. Also, performance should improve when postural control is challenged[15,19] and participants perform on the balance beam (as opposed to when they are standing on even ground). The second aim is to investigate if the different demands on dynamic stability are reflected in postural sway parameters. Here, it is expected that performing the MBRT improves postural stability (as signified by postural sway parameters), as compared to a control condition.[20,21]

METHODS

Sample

The study was carried out in accordance with the Helsinki Declaration of 1957 and was approved by the local ethics committee of the university. A total of 30 sport science students (18 females, mean age = 21.2 years, age range 18-25 years, 4 left-handers; 12 males, mean age = 21.3 years, age range 19-28 years, 2 left-handers) with normal or corrected-to-normal vision participated in the current experiment. All of them received course credits, but there was no financial or other benefit for participation. Prior to the experiment, all participants signed an informed consent form and filled out a short questionnaire. They were all native German speakers, characterized themselves as neurologically healthy, and none of them took part in a comparable mental rotation experiment before. The physical activity background of the participants ranged from team sports (e.g., soccer, basketball, handball, and hockey), to individual sports (e.g., swimming, fitness, and weight training), to outdoor activities (e.g., jogging, and mountain bike).

Apparatus

A projector (Optoma) presented the stimuli onto a wall in the laboratory by using the software “Presentation” (Version 20.2, Neurobehavioral Systems). Participants viewed the experimental stimuli either standing on a wooden balance beam (86cm x 9cm x 4.5cm) or standing on a force plate (AMTI, 60cm x 90cm, sample frequency 1000 Hz), 3 meters away from the wall.[22] When standing on the beam, participants adopted the tandem stand position (one feet behind the other; heel-to-toe position). When standing on the force plate, participants adopted the feet parallel position. Force plate data were recorded by Simi Motion (Version 9.0.2, Simi Reality Motion Systems). The stimuli appeared in a size of 100 cm in diameter[22] on a black screen. Verbal responses were given with a microphone (Rhode) linked via an usb-port with the computer. The experimental set-up can be seen in Figure 1.

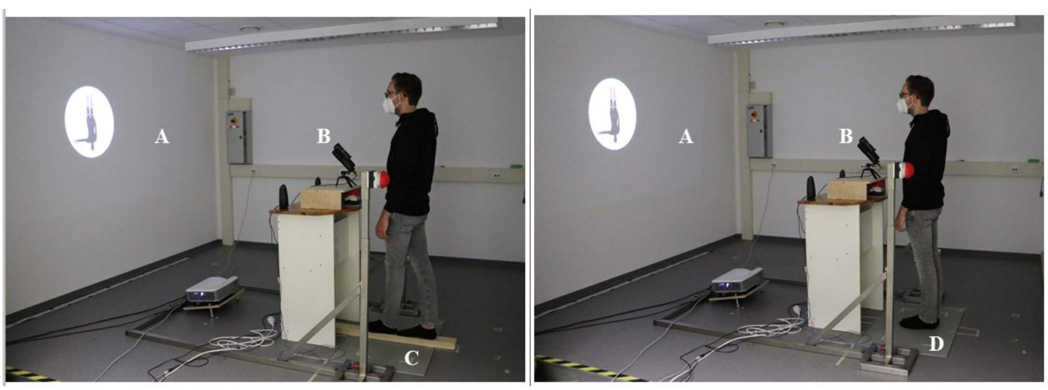

Figure 1. Experimental set-up. Picture of the experimental set-up with the two standing positions (left: tandem, right: parallel). A: wall on which the stimuli were projected, B: microphone, C: balance beam, D: force plate.

Stimulus Material

The stimuli for the two different MBRTs were taken from Steggemann and colleagues.[23] One of the tasks required an object-based spatial transformation and the other an egocentric perspective transformation (see Figure 2). In the object-based transformation, two images of a female person in back view perspective and with either the left or the right arm extended were presented simultaneously on a black screen, one next to the other. These images were either identical or mirror image reversals of each other. In each pair, the left image was arranged in an upright position (0°) and the orientation of the image at the right was rotated randomly in the picture plane (clockwise 0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°), yielding in 32 different stimuli. Half of the trials presented pairs of identical objects and half displayed mirror-reversed objects, resulting in a same-different-judgment.

In the egocentric perspective transformation, a single image, depicting a female person with the left or the right arm outstretched, appeared on a black screen. Therefore, a left-right decision was required. The person in the image was presented from back view and rotated randomly in the picture plane (clockwise 0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°), resulting in 16 different stimuli.

Additionally, there was one control condition, which did not use a mental rotation task. Instead, in this condition a color-naming task was used in which a yellow or a blue circle was presented on a black screen, resulting in two different stimuli (see Figure 2).

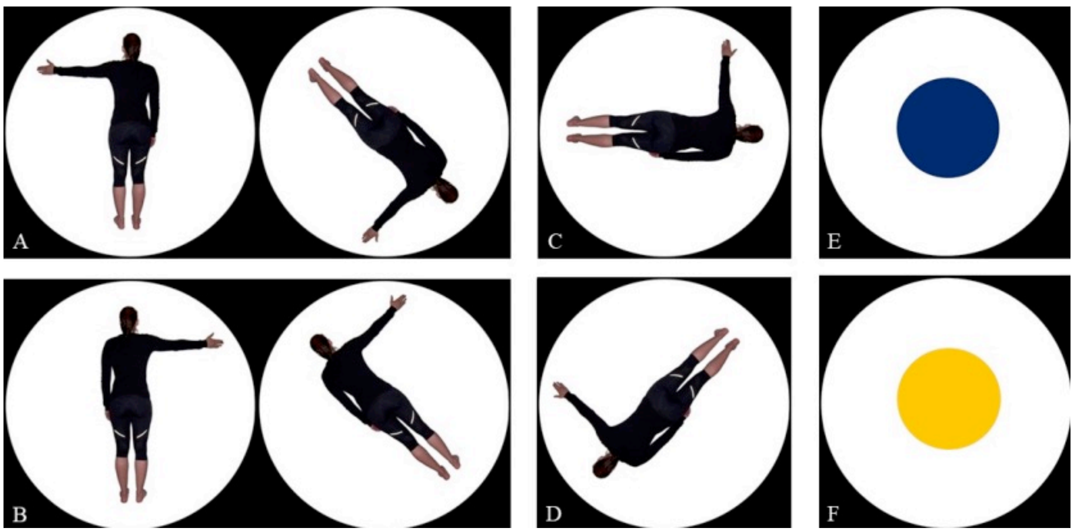

Figure 2. Examples of stimuli used in the experiment. (A) same-different judgment with 135° angular disparity, different pictures; (B) same-different judgment with 315° angular disparity, same pictures; (C) left-right judgment with 90° angular disparity, left arm outstretched; (D) left-right judgment with 225° angular disparity, right arm outstretched; (E) control condition, blue circle; (F) control condition, yellow circle.

Procedure and task

The test session lasted about 40-45 minutes and took part in the laboratory at the university. After filling out a short questionnaire and given informed consent, participants could read the standardized task introductions on their own. In the object-based spatial transformation, participants had to decide as quickly and as accurate as possible if the two images presented simultaneously were the same (i.e., copies that differ only in rotation angle) or different (i.e., mirror-reversed images). They had to answer “gleich” (German word for “same”), when the two stimuli were the same, and “ungleich” (German word for “different”), when the two stimuli were different. In the egocentric perspective transformation, participants were asked to determine as quickly and as accurate as possible whether the presented person raised her left or her right arm. They had to answer “links” (German word for “left”), when the left arm was raised, or to answer “rechts” (German word for “right”), when the right arm was raised. In the control condition (i.e., color-naming task) participants had to answer “gelb” (German word for “yellow”), when the yellow circle appeared, or to answer “blau” (German word for “blue”), when the blue circle appeared.

The three tasks were performed while standing in a tandem stand on a balance beam and while standing in a parallel stand position on a force plate. There was a mark on the force plate to standardize the position of the two feet. Thus, participants placed their feet in the same position for all experimental conditions. The order of the tasks, as well as the order of the postures (parallel stand vs. tandem stand), was counterbalanced across participants. There were 64 experimental trials in each condition, resulting in 384 trials for the entire experiment.

In the object-based transformation task, each combination of the eight angular disparities of the right picture (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°), the stimulus pairs (same or different), and the two images (original or mirrored) was presented two times in each test block. Half of the trials showed the same and the other half showed different images. The 64 trials in the egocentric transformation task were composed of two stimulus types (person with left or right arm raised) x eight angular disparities (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°) x four repetitions of each combination. Half of the trials showed the person raising the left arm and half of the trials displayed the person raising the right arm. In the color-naming task, each circle color was presented 32 times. The order of the presentation of the stimuli in all conditions was randomized. To familiarize themselves with the stimuli and the tasks, participants performed a practice session with 16 trials before each new task. The order of the trials within the practice session was randomized for the egocentric transformation and the control condition, and pseudo-randomized for the object-based transformation. Between the blocks, participants could decide how long they wanted to have a break.

Each trial started with a black screen. After 500 ms, a white fixation cross appeared for 500 ms, whereupon the stimuli were presented. The stimuli stayed on the screen until participants answered. In the case of a wrong answer, participants immediately received feedback and the word “Fehler” (German word for “error”) appeared on the screen. This feedback was given for 1000 ms.

Data analysis

Response time and response error

Response time and response error were analyzed with two three-way analyses of variance (ANOVAs), including the repeated factors task (object-based vs. egocentric transformation), rotation angle (0°, 45°/315°, 90°/270°, 135°/225°, 180°), and posture (parallel stand vs. tandem stand), as independent variables, and response time (RT) and response error (RE), as dependent variables. RTs faster than 100 ms (0 %) and slower than 2500 ms (1,38 %) were defined as outliers and excluded from statistical analysis, as well as data from incorrect trials (2,03 %). The incorrect trials were separately analyzed in another ANOVA. Data from the practice sessions were not analyzed. The Greenhouse-Geisser adjustment was used to correct for violations of sphericity and post-hoc t-test were Bonferroni-Holm adjusted.

Force plate data

Postural control performance was examined using the Center of Pressure (CoP) obtained from the force plate. CoP values for both anterior-posterior (AP) and medial-lateral (ML) directions were first low-pass filtered at 10 Hz with Hemming-window. CoP values were grouped based upon each of the valid trial. In this case, each valid sequence of CoP started at the moment that stimulus was presented and lasted until the moment of the fastest RT plus 1000 ms. After defining these CoP intervals, the maximum range of oscillation, for both AP and ML directions, was computed as the difference between the maximum and minimum values of CoP within each sequence. In addition, the overall sway velocity was calculated as the sum of the CoP displacement in both AP and ML directions, within each sequence, divided by the total time of this sequence. Maximum range and overall velocity values were grouped in each MBRT conditions (object-based and egocentric transformations) and rotational angles, resulting in five mean values for clockwise and anti-clockwise measurements (0°, 45°/315°, 90°/270°, 135°/225°, 180°). For the control condition, there was only one sequence over time per participant.

To compare the two MBRTs (0° rotation angle) and the control condition, three repeated measures ANOVAs, with condition as factor, were employed. In addition, three two-way repeated measures ANOVAs, with the MBRT conditions and rotation angles as factors, were conducted. Dependent variables for all these ANOVAs were the maximum range for AP and ML directions and the overall sway velocity.

RESULTS

Response time (RT)

Figure 3 provides the RT pattern for both postures in the object-based transformation and the egocentric perspective transformation. The ANOVA revealed a main effect of condition, F (1, 29) = 140.43, $p < .001$, $\eta^2_p = .83$, showing that participants were significantly faster in the egocentric transformation task (M = 683 ms) than in the object-based transformation task (M = 984 ms). The ANOVA also revealed a main effect of rotation angle F (1.5, 44.5) = 174.39, $p < .001$, $\eta^2_p = .86$, with the RT steadily increasing. Post-hoc t-test indicated that RT differed significantly from each angular disparity to the proximate one (all $p < .001$). The ANOVA also revealed condition and rotation angle interaction (F (2, 58) = 18.71, $p < .001$, $\eta^2_p = .39$), whereupon the rotation angle had a greater impact on object-based transformation. Post-hoc t-test showed significant differences of means for all increases in angular disparity (all $p < .01$), except for between 135° and 180° ($p = .584$). There was no main effect for posture and no significant two-way interaction, neither between condition and posture, nor between posture and rotation angle. Furthermore, the three-way interaction between condition, rotation angle, and posture also failed to reach significance.

Response Error (RE)

The RE pattern for the two postures in the object-based transformation and in the egocentric transformation can be seen from Figure 3. The ANOVA revealed a main effect of condition (F (1, 29) = 41.03, $p < .001$, $\eta^2_p = .59$). Accordingly, participants committed significantly more errors in the object-based transformation (3.6 %) than in the egocentric transformation (1.1 %). The ANOVA also revealed a main effect for rotation angle (F (1.69, 48.88) = 14.13, $p < .001$, $\eta^2_p = .33$). Post-hoc t-test showed that RE differed significant between all rotation angles (all $p < .05$), except for between 135° and 180° ($p = .054$). Differently, the ANOVA did not reveal a main effect for posture and no significant two-way interaction. Similarly, the ANOVA did not reveal a significant three-way interaction (condition, posture, and rotation angle).

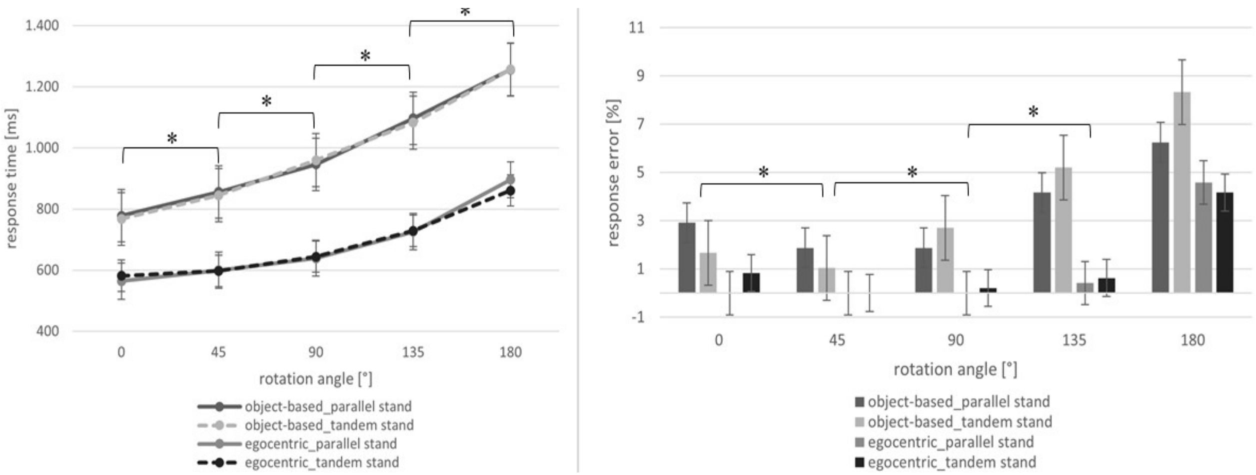

Figure 3. Response Time (RT) and Response Error (RE). Left: Mean response times (RT) in milliseconds (SD) for the object-based transformation and the egocentric transformation. Right: Mean response errors (RE) as percentages (SD) for the object-based transformation and the egocentric transformation.

Center of Pressure (CoP)

CoP maximum range for both AP and ML directions and overall sway velocity values for the three conditions are presented in Table 1. Specific comparisons among these conditions are presented below.

Table 1 – *Mean CoP parameters for the three different conditions*

Parameter	Conditions										
	object-based					egocentric					control
	0°	45°	90°	135°	180°	0°	45°	90°	135°	180°	
range ap [mm]	7.45 (4.12)	6.97 (3.06)	7.24 (3.02)	7.78 (3.69)	6.47 (2.35)	5.79 (2.47)	5.99 (2.71)	6.21 (2.88)	6.30 (2.92)	6.14 (2.92)	6.86 (2.00)
range ml [mm]	5.78 (2.04)	5.97 (2.26)	5.68 (2.11)	6.23 (2.41)	5.54 (1.98)	4.80 (1.59)	5.17 (1.74)	5.03 (1.69)	5.28 (1.91)	5.26 (1.80)	5.43 (1.76)
sv [mm/s]	13.38 (4.69)	13.56 (3.94)	12.91 (3.59)	13.47 (3.97)	13.13 (4.19)	12.52 (3.11)	12.77 (3.73)	12.26 (3.39)	12.12 (3.30)	12.10 (3.36)	13.06 (3.12)

Note. Mean values (SD) for the three conditions and the different rotation angles. Range ap = maximum range of CoP in anterior-posterior direction, range ml = maximum range of CoP in medial-lateral direction, sv = sway velocity.

MBRT and control condition

Figure 4 depicts maximum range of CoP for both AP and ML directions and the overall velocity of CoP for the two MBRTs and control condition. For the maximum range in the AP direction, the ANOVA revealed a significant condition effect (F (2, 58) = 4.30, p = .018, η^2_p = .13). Post-hoc t-tests showed that the CoP range in the egocentric (M = 5.79 mm) transformation differed significant from the object-based (M = 7.45 mm) transformation (p = .042) and the control (M = 6.86 mm) condition (p = .046). There was no significant difference between the object-based and the control condition. For the maximum range in the ML direction, the ANOVA also revealed a significant condition effect (F (1.66, 48.12) = 4.91, p = .016, η^2_p = .15). Accordingly, the range in the object-based transformation was highest (M = 5.79 mm) when compared to the control condition (M = 5.49 mm) and the egocentric transformation (M = 4.80 mm). Post-hoc t-tests showed that there is a significant difference between the egocentric and the object-based transformation (p = .048), but these two MBRT did not differ from the control condition (all p > .05). For the overall CoP velocity, the ANOVA did not reveal a significant condition effect (F (1.66, 48.12) = 4.91, p > .05, η^2_p = .15).

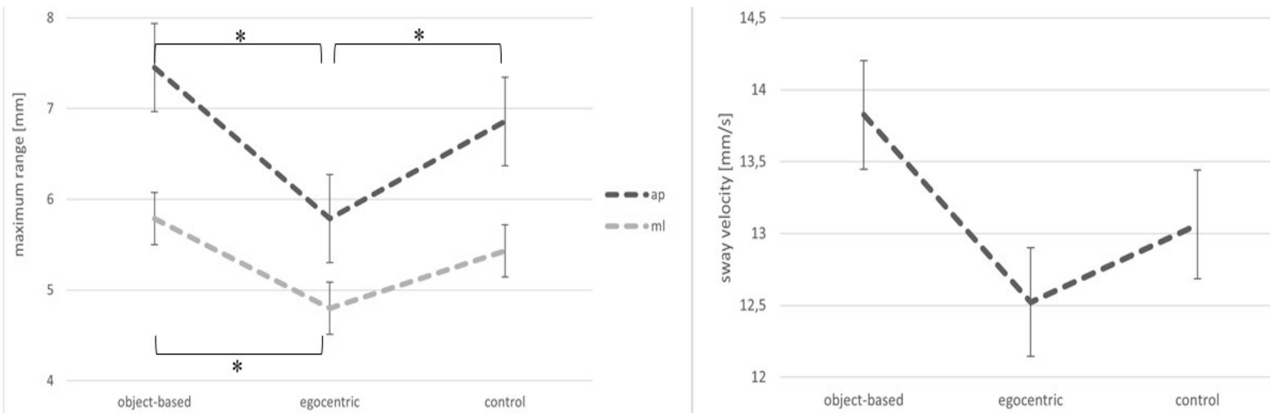

Figure 4. Comparison MBRT and control condition. Left: Mean values (SD) of maximum range of CoP in anterior-posterior (ap) and medial-lateral (ml) direction. Right: Mean values (SD) of sway velocity of CoP for the two MBRT (object-based and egocentric) and the control condition.

MBRT and rotation angles

Figure 5 depicts CoP maximum range for both AP and ML directions and for both MBRT conditions and all rotation angles. For the maximum range in the AP direction, the ANOVA revealed a significant main effect for condition (F (1, 29) = 10.78, p = .003, η^2_p = .27), with a higher range in the object-based transformation (M = 7.18 mm) compared to the egocentric one (M = 6.08 mm), and a main effect for rotation angle (F (2.79, 81.00) = 2.93, p = .042, η^2_p = .09). Post- hoc t-tests revealed only a significant difference between rotation angle 45° and 135° (p = .01) and between 135° and 180° (p = .018). The ANOVA did not reveal a significant condition and rotation angle interaction (p = .086). For the maximum range in the ML direction, the ANOVA revealed a significant main effect for condition (F (1, 29) = 11.50, p = .002, η^2_p = .28), with a lower range in the egocentric (M = 5.11 mm) compared to the object-based transformation (M = 5.84 mm), but no effect for rotation angle (p = .140) nor a significant condition and rotation angle interaction (p = .246).

Figure 6 depicts CoP overall velocity for both MBRT conditions and all rotation angles. The ANOVA revealed a significant main effect for condition (F (1, 29) = 4.57, p = .041, η^2_p = .14), with a higher sway velocity in the object-based (M = 13.38 mm/s) compared to the egocentric transformation (M = 12.35 mm/s), but no main effect for rotation angle (p = .104) nor a significant condition and rotation angle interaction (p = .682).

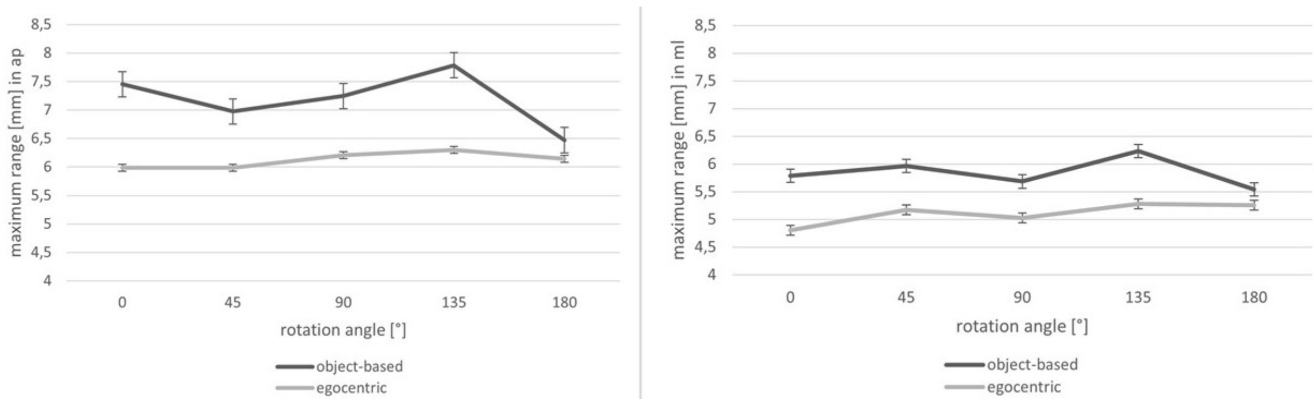

Figure 5. Maximum range of CoP. Left: Mean values (SD) of maximum range of CoP in anterior-posterior (ap) direction for both MBRT and all five rotation angles. Right: Mean values (SD) of maximum range of CoP in medial-lateral (ml) direction for both MBRT and all five rotation angles.

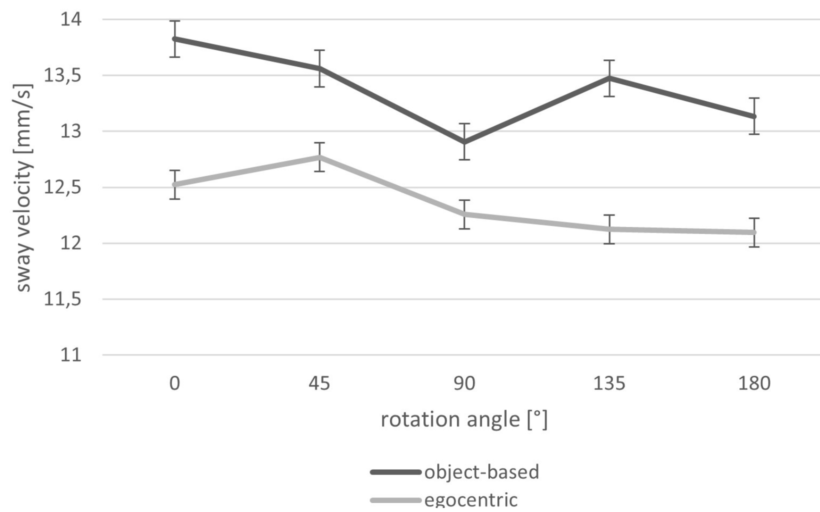

Figure 6. Sway velocity of CoP. Mean values (SD) of sway velocity of CoP for both MBRT and all five rotation angles.

DISCUSSION

The present study investigated the relationship between postural control and mental body rotation. To this end, participants performed in two MBRTs and a control task without any mental rotation. All tasks were solved while standing in the tandem position on a balance beam or with both feet parallel on a force plate.

The results show that RTs and REs increase for visual-spatial transformations of human bodies, the more the stimuli must be mentally rotated. This is in line with predictions derived from previous studies on the mental rotation of human bodies.[8,9,10,11,18,23] Moreover, participants performed better for egocentric perspective transformations than for object-based transformations, as reflected in faster response times and fewer response errors. Our prediction, that the performance in a MBRT is better when using egocentric perspective transformation strategy was confirmed. Furthermore, this supports the notion that aligning oneself into the person displayed is faster than to spatially align and compare two objects.[11,24]

The embodied cognition approach states that mental and motor processes cannot be separated from each other and therefore embodiment can help to encode and spatially represent rotated stimuli.[16,17,25] Following this assumption and taking into consideration that a previous study on the perception of visual orientation demonstrated better performance when the postural control of participants was challenged,[15] it was expected that this is also true for the performance in a MBRT. However, the position in which participants solved the MBRT (parallel stand vs. tandem stand) did not lead to any effects on participants´ mental rotation performance. In the present study, as well as in our previous study,[18] participants were similarly able to map their own body representation to the presented figure while being tested in different positions, indicating that these postural changes did not influence the performance in the MBRT. Therefore, our prediction that participants performance improves when they were balancing compared to when they were standing was not confirmed. This contrasts with the observation that, as soon as the basis of support is manipulated, the link between body sway and visual information is increased in young and older adults.[26] Maybe embodied processes had no effect on participants´ performance, because postural control processes (i.e., keeping balance) do not interfere with perceptual-cognitive processes (i.e., performing mental body-rotations). Therefore, in a further study, postural control may be challenged to an even greater degree by performing the tasks, for example, while standing on a vibration board. Another limitation of the study is that only young and healthy sport science students performed the tasks. Maybe the challenges of postural control were too easy for these participants. Future studies should therefore examine if there are comparable results when the tasks are performed by elderly or by children in the same postures.

The second aim of the present study was to examine if different demands on dynamic stability are reflected in postural sway parameters, as it was demonstrated in previous studies, in which the authors found a correlation between mental rotation performance and postural sway parameters.[19,20,21] When comparing the MBRTs and the control condition, there was no significant difference (except the egocentric transformation and control condition in anterior-posterior direction) between the tasks. Therefore, performing a MBRT does not seem to affect postural sway parameters and our prediction, that a MBRT leads to more postural stability than a control task could not be confirmed. This is in contrast to the findings by Hofmann and Jansen,[21] who found a significant influence with decreasing postural sway parameters while solving the mental rotation task. However, this was only true when participant´s performance was compared to the first control condition of this study in which they were just looking at a fixation cross and doing nothing. The second control condition of the Hofmann and Jansen[21] study was a math task and when comparing this condition to the mental rotation tasks there was no difference in terms of body sway at all.[21] This was also the case in the study by Dault and colleagues,[20] who just found that a mental rotation task with stickman as stimuli led to more postural stability, as compared to a no-mental-task condition, but there were no differences between the mental rotation task and other working memory tasks. The authors stated that this indicates that the addition of a task, regardless from its difficulty, leads to postural stabilization.[20,21] It is speculative if this is also the case in our study, because we did not have a control condition in which participants had to do nothing, which could be seen as a further limitation of our study.

Most interestingly, however, our results provide evidence for different amounts of stabilization between the two MBRTs, meaning that the egocentric transformation task leads to more postural stability than the object-based transformation task, which is reflected in a lower range of motion in anterior-posterior and medial-lateral direction and a lower sway velocity. This is in line with the results by Hofmann and Jansen,[21] even though they found the difference between an egocentric transformation task and an object-based transformation task with cube figures as stimuli. Nevertheless, the results are surprising regarding the different perspectives of motor imagery. According to Stins and colleagues[13] and Zacks and Michelon,[14] the kinesthetic perspective distinguished that a person imagines performing the movement himself/herself, while the visual perspective states that a person imagines another person performing the movement. Therefore, an egocentric transformation task with embodied stimuli is consistent with the kinesthetic perspective and one would expect that solving this kind of MBRT generates more body sway than an object-based transformation task. However, the values for the maximum range in anterior-posterior and medial-lateral direction were higher in the object-based transformation task, indicating more instability compared to the egocentric transformation task. One explanation could be the difficulty of the tasks. Although, we did not ask the participants, which task they would classify as more difficult, from the higher response times and higher error rates it can be derived that the object-based transformation task seems to be more difficult than the egocentric one. These observations are a hint, that task difficulty has an impact on body sway with increasing difficulty leading to an increase in postural sway.[21] Regarding the rotation angle, the results only revealed an influence in the anterior-posterior direction. A significant difference was found between 45° and 135° angular disparity and between 135° and 180°. This reflects that higher rotation angles lead to more postural sway, which was also mentioned in previous studies.[19,21] However, this is very speculative and must be viewed with caution because the influence of rotation angle was only found in one of the analyzed parameters. To conclude, the present results are in line with those of previous studies[20,21] and hold also true when using pictures of a real person as stimuli and when presenting a large number of trials in each condition. Most interestingly, in contrast to previous studies,[20,21] the present results revealed a reduction of body sway during the MBRT for egocentric perspective transformations compared to object-based transformations, suggesting different mechanism to affect dynamic stability under these conditions.

CONCLUSION

In summary, the present study was designed to investigate the relation between postural control and mental body rotation. The results revealed no influence of posture on the performance in a MBRT when comparing standing on a balance beam in a tandem stand with standing in a parallel stand position on even ground. Furthermore, performing a MBRT while standing in a parallel stand position is reflected in the same postural sway parameters as when performing a no-mental-rotation task. However, there is a difference between the MBRTs, indicating that an egocentric transformation task leads to more postural stability, as compared to an object-based transformation task with human bodies.

REFERENCES

1. Steggemann-Weinrich Y, Weigelt, M. Mental rotation skills. In: Hackfort D, Schinke RJ, Strauss B, editors. *Dictionary of Sport Psychology - Sport, Exercise, and Performing Arts*. London, UK: Academic Press; 2019. p.173.
2. Shepard RN, Metzler J. Mental rotation of three-dimensional objects. *Science*. 1971;171(3972):701-703. https://doi.org/10.1126/science.171.3972.701
3. Cooper LA. Mental rotation of random two-dimensional shapes. *Cognitive Psychology*. 1975;7(1):20-43.
4. Kaltner S, Jansen P. Developmental changes in mental rotation: a dissociation between object-based and egocentric transformations. *Advances in Cognitive Psychology*. 2016;12(2):67-78. https://doi.org/10.5709/acp-0187-y
5. Voyer D, Jansen P, Kaltner S. Mental rotation with egocentric and object-based transformations. *The Quarterly Journal of Experimental Psychology*. 2017;70(11):2319-2330. http://dx.doi.org/10.1080/17470218.2016.1233571
6. Bläsing B, Brugger P, Weigelt M, Schack T. Does thumb posture influence the mental rotation of hands? *Neuroscience Letters*. 2013;534:139-144. http://dx.doi.org/10.1016/j.neulet.2012.11.034
7. Amorim MA, Isableu B, Jarraya M. Embodied spatial transformations: "Body analogy" for the mental rotation of objects. *Journal of Experimental Psychology: General*. 2006;135(3):327-347. https://doi.org/10.1037/0096-3445.135.3.327
8. Kaltner S, Jansen P. Sex of human stimulus matters: female and male stimuli are processed differently in mental rotation tasks*. Journal of Cognitive Psychology*. 2018;30(8):854-862. https://doi.org/10.1080/20445911.2018.1530677
9. Kaltner S, Riecke BE, Jansen P. Embodied mental rotation: A special link between egocentric transformation and the bodily self. *Frontiers in Psychology*. 2014;5(505):1-11. https://doi.org/10.3389/fpsyg.2014.00505
10. Pietsch S, Jansen P. Mental rotation and handedness: differences in object-based and egocentric transformations. *Journal of Cognitive Psychology*. 2018;30(5-6):511-519. https://doi.org/10.1080/20445911.2018.1483937
11. Jola C, Mast FW. Mental object rotation and egocentric body transformation: Two dissociable processes? *Spatial Cognition & Computation*. 2005;5(2-3):217-237. https://doi.org/10.1080/13875868.2005.9683804
12. Zacks JM, Mires J, Tversky B, Hazeltine E. Mental spatial transformations of objects and perspective. *Spatial Cognition and Computation*. 2002;2(4):315-332. https://doi.org/10.1023/A:1015584100204
13. Stins JF, Schneider IK, Koole SL, Beek PJ. The influence of motor imagery on postural sway: differential effects of type of body movement and person perspective. *Advances in Cognitive Psychology*. 2015;11(3):77-83. http://doi.org/10.5709/acp-0173-x
14. Zacks JM, Michelon P. Transformations of visuospatial images. *Behavioral and Cognitive Neuroscience Reviews*. 2005;4(2):96-118. https://doi.org/10.1177/1534582305281085

15. Bray A, Subanandan A, Isableu B, Ohlmann T, Golding JF, Gresty MA. We are most aware of our place in the world when about to fall. *Current Biology*. 2004;14(15): R609-R610. https://doi.org/10.1016/j.cub.2004.07.040
16. Barsalou LW. Perceptual symbol systems. *Behavioral and Brain Sciences*. 1999;22:577-660. https://doi.org/10.1017/S0140525X99002149
17. Wilson M. Six views of embodied cognition. *Psychonomic Bulletin & Review*. 2002;9:625-636. https://doi.org/10.3758/BF03196322
18. Budde K, Barela JA, Figueiredo GA, Weigelt M. Mental body rotation with egocentric and object-based transformations in different postures: sitting vs. standing. *Brazilian Journal of Motor Behavior*. 2020;14(2):73-84. https://doi.org/10.20338/bjmb.v14i2.165
19. Kawasaki T, Yasuda K, Fukuhara K, Higuchi T. Relationship between mental rotation of body parts and postural stability during quiet stance. *Journal of Imagery Research in Sport and Physical Activity*. 2014;9(1):39-46. https://doi.org/10.1515/jirspa-2014-0001
20. Dault MC, Frank JS, Allard F. Influence of a visuo-spatial, verbal and central executive working memory task on postural control. *Gait and Posture*. 2001;14(2):110-116. https://doi.org/10.1016/S0966-6362(01)00113-8
21. Hofmann P, Jansen P. The relation of mental rotation and postural stability. *Journal of Motor Behavior*. 2021;1-15. https://doi.org/10.1080/00222895.2021.1899113
22. Kaltner S, Jansen P, Riecke BE. Stimulus size matters: do life-sized stimuli induce stronger embodiment effects in mental rotation? *Journal of Cognitive Psychology*. 2017;701-716. https://doi.org/10.1080/20445911.2017.1310108
23. Steggemann Y, Engbert K, Weigelt M. Selective effects of motor expertise in mental body rotation tasks: comparing object-based and perspective transformations. *Brain and Cognition*. 2011;76(1):97-105. https://doi.org/10.1016/j.bandc.2011.02.013
24. Parsons LM. Imagined spatial transformation of one's body. *Journal of Experimental Psychology: General*. 1987;116(2):172-191.
25. Wexler M, Kosslyn SM, Berthoz A. Motor processes in mental rotation. *Cognition*. 1998;68(1):77-94. https://doi.org/10.1016/S0010-0277(98)00032-8
26. Prioli AC, Cardozo AS, de Freitas Júnior PB, Barela JA. Task demand effects on postural control in older adults. *Human Movement Science*. 2006;25(3):435-446. https://doi.org/10.1016/j.humov.2006.03.003

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