Paderborn University

Faculty of Science
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Mental Body Rotation in Sports

Cognitive Foundations and the Influence of different Perturbations on the Performance in Mental Body Rotation Tasks with Egocentric and Object-Based Transformations

Cumulative Dissertation

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Reviewer

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Abstract

Although controlling dynamic stability during upright stance appears to be relatively easy, at least for adults, the typical test scenario employed in laboratory research on mental rotation examines participants' performance while they are seated in a chair. Consequently, the relationship between postural control and the cognitive task of mental rotation remains poorly understood. Motivated by the theoretical framework of embodied cognition, the overarching aim of this dissertation is to illuminate the relationship between postural control and mental rotation of human bodies in a mental body-rotation task (MBRT). To achieve this aim, four experiments were conducted, with the level of challenge to balance control gradually increasing in each subsequent experiment. The results demonstrated that there were no statistically significant differences between the performance of the MBRT in a parallel standing position on even ground (low demands), standing on a balance beam or a balance board (high demands), or standing on a vibrating platform with varying levels of vibration intensity. It may therefore be the case that postural control processes do not interfere with perceptual-cognitive processes, and that embodied processes may not have influenced the performance of the participants. Moreover, performing a MBRT while standing in a parallel position resulted in postural sway parameters that were similar to those observed in a no-mental-rotation task. However, a notable distinction was observed between the two types of MBRTs: an egocentric transformation task led to greater postural stability compared to an object-based transformation task. Further studies should be conducted to determine whether this pattern of results is also applicable to participants of other age groups, including older adults, children, and adolescents.

Zusammenfassung

Obwohl das aufrechte Stehen, zumindest für Erwachsene, einfach zu sein scheint, werden die Teilnehmenden in der Laborforschung zur mentalen Rotation typischerweise im Sitzen getestet. Folglich ist der Zusammenhang zwischen der posturalen Kontrolle und dem Lösen einer mentalen Rotationsaufgabe bis dato kaum untersucht. Vor dem Hintergrund der Embodiment-Theorie ist das übergreifend Ziel dieser Dissertation, die Beziehung zwischen posturaler Kontrolle und dem Lösen einer mentalen Rotationsaufgabe mit menschlichen Stimuli (MBRT) zu beleuchten. Um dieses Ziel zu erreichen, wurden vier Experimente durchgeführt, wobei der Schwierigkeitsgrad der Gleichgewichtskontrolle von Experiment zu Experiment schrittweise erhöht wurde. Die Ergebnisse zeigten, dass es keine statistisch signifikanten Unterschiede zwischen der Durchführung der MBRT im parallelen Stand auf ebenem Untergrund (niedrige Anforderungen), im Stehen auf einem Balancierbalken oder einem Balancierkreisel (hohe Anforderungen), oder im Stehen auf einer Vibrationsplatte mit unterschiedlicher Vibrationsintensität gab. Ein möglicher Erklärungsansatz ist, dass die Prozesse der Haltungskontrolle nicht mit den wahrnehmungsbezogenen kognitiven Prozessen interferieren und die Embodiment-Prozesse die Leistung der Teilnehmenden nicht beeinflusst haben. Darüber hinaus führte die Durchführung einer MBRT zu ähnlichen Haltungsschwankungsparametern wie die Durchführung einer kognitiven Aufgabe ohne mentale Rotation. Die Ergebnisse zeigten jedoch einen Unterschied zwischen den beiden Arten von MBRTs: Eine egozentrische Transformationsaufgabe führte zu einer größeren Haltungsstabilität im Vergleich zu einer objektbasierten Transformationsaufgabe. Um zu prüfen, ob dieses Ergebnismuster auch auf Teilnehmende anderer Altersgruppen (ältere Erwachsene, Kinder, Jugendliche) übertragbar ist, bedarf es weiterer Studien.

Content

List of Publications

Peer-reviewed Journal Articles

Budde, K., Barela, J. A., Figueiredo, G. A., & Weigelt, M. (2020). Mental body rotation with egocentric and object-based transformations in different postures: sitting vs. standing. *Brazilian Journal of Motor Behavior, 14*(2), 73-84.

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Oral Presentations

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Budde, K., Barela, J. A., & Weigelt, M. (2020). Hat die Körperposition (sitzen vs. stehen) einen Einfluss auf die Leistung in einer Mentalen Rotationsaufgabe? In G. Amesberger, S. Würth, T. Finkenzeller (Eds.), *Abstractband Der 52. Jahrestagung Der Arbeitsgemeinschaft Für Sportpsychologie (Asp)* (p. 40).

List of Abbreviation

ap	anterior-posterior
CoG	Center of Gravity
CoM	Center of Mass
CoP	Center of Pressure
e.g.	exempli gratia, for example
et al.	et alii, and others
i.e.	id est, that is
MBRT(s)	mental body-rotation tasks(s)
ml	medial-lateral
MR	mental rotation
MRT	mental rotation task
ms	millisecond(s)
PET	positron emission tomography
RE(s)	response error(s)
RT(s)	response time(s)
sec.	second(s)
vs.	versus

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1 Introduction

First introduced by Shepard and Metzler (1971), the mental rotation task (MRT) has become a widely used paradigm in cognitive psychology and examines peoples' "*ability to spatially transform two-dimensional or three-dimensional objects or bodies from one orientation in mental space to another*" (Steggemann-Weinrich & Weigelt, 2019, p. 173). Mental rotation (MR), as a cognitive task, has been the focus of many empirical studies (e.g., influence of gender [Jansen & Heil, 2009; Linn & Petersen, 1985; Voyer et al., 1995], influence of age [Berg et al., 1982; Jansen & Heil, 2009; Titze et al., 2010], influence of expertise [Feng et al., 2017; Habacha et al., 2022; Steggemann et al., 2011]). However, one aspect that has received less attention in the past is the relationship between mental rotation and postural control. Since mental rotation ability is closely linked to spatial abilities, which play an important role in everyday life, the interference with other everyday processes, such as motor processes, are also important. In this context, maintaining postural control is an essential skill necessary for standing upright. The typical test scenario of laboratory research in mental rotation examines participants' performance while they are sitting on a chair (e.g., Budde et al., 2020; Habacha et al., 2017; Kaltner et al., 2014; Krause & Weigelt, 2023; Pietsch & Jansen, 2018; Steggemann et al., 2011). Although standing upright may appear to be an easy motor task, and not significantly more difficult compared to sitting on a chair while performing mental rotation experiments, a closer look reveals that controlling dynamic stability during upright stance is actually a complex process that involves multiple mechanisms to accomplish this seemingly simple task. This activity includes the innervation of muscles distributed throughout the entire body. A geometric relationship with the environment must be maintained by multiple distributed joints and muscle groups. To maintain the desired position of the body as a whole with respect to the environment, the central nervous system needs to find appropriate relationships between the segments of the body (e.g. Balasubramaniam & Wing, 2002). The maintenance of posture depends on the balance between the resultant external torque and the torque developed by the muscles acting around the joint (e.g., Balasubramaniam & Wing, 2002). External disturbances, such as forces resulting from gravity, external events, like a moving platform, or one's own actions, such as moving the head or lifting an arm, can be a challenge to one's balance and a cause of loss of equilibrium (e.g., Balasubramaniam & Wing, 2002). It is important to note that cognitive tasks can also be considered a "form of disturbance". That is, because individuals usually perform a cognitive and a motor task simultaneously, which constitutes a dual-task scenario (e.g., Pashler, 1994). It is assumed that there is a dual-task-related decrease in performance (signified by dual-task costs) compared to when each task is performed alone. This is because both tasks compete for similar information processing resources. Although standing upright calmly appears to be a simple motor task, studies have shown that it can also be influenced by a cognitive task performed simultaneously (e.g., Andersson et al., 2002; Mujdeci et al., 2016). The results, however, have been inconsistent so far. Research has shown that performing the cognitive task can stabilize balance (Andersson et al., 2002; Hunter & Hoffman, 2001; Potvin-Desrochers et al., 2017; Vuillerme et al., 2000), but evidence also exists that simultaneous task performance can lead to destabilizing (Mujdeci et al., 2016; Pellecchia, 2003; Simoneau et al., 1999). In addition, and somewhat surprising, when dynamic stability is challenged, studies have found improved performance in visuospatial processing (e.g., Bray et al., 2004; Prioli et al., 2006). As mentioned earlier, there are currently only a few studies that have examined the relationship between mental rotation (as a cognitive task) and postural control (as a motor task). For example, Dault and colleagues (2001) examined how different working memory tasks, as well as a mental rotation task, affected postural stability. When the mental rotation task was compared to a control condition, the results showed a reduction in body sway for the mental rotation task. However, when comparing the mental rotation task to other working memory tasks, there was no effect on body sway. A comparable pattern of result was found by Hofmann and Jansen (2021). Their study demonstrated a reduction in body sway in the mental rotation task compared to a neutral condition but no differences in body sway when comparing the mental rotation task with another cognitive task.

Out of this research gap, the motivation for the following thesis arose. The overall purpose of this dissertation is to shed light on the relationship between postural control (i.e. keeping balance) and mental rotation of human bodies in a so-called mental body-rotation task (MBRT, Jola & Mast, 2005). In spatial cognition, three types of mental transformation strategies (see Chapter 2.3.3) can be distinguished, namely an *object-based transformation* and an *egocentric perspective transformation* strategy (Zacks et al., 2000). For object-based transformations, the observer mentally rotates the object relative to a reference frame in the environment, while keeping their own position fixed. For egocentric perspective transformations, the observer's point of view relative to a reference frame is updated, while the position between an object and the environment remains fixed.

According to the embodied cognition framework (see Chapter 2.1), egocentric and object-based transformations may benefit from involving motor processes. It appears that mental rotation skills, previously believed to be solely based on cognitive processes, may also involve a motor component. This means, when performing a cognitive task, our body and corresponding motions are also involved, not just our brain (e.g., Wilson, 2002). In the context of mental rotation skills, two types of embodiment can account for the performance of spatial transformations. The concept of spatial embodiment suggests that one's own body axis is projected onto the object being embodied. The second concept is motoric embodiment, which posits that the processes of imagining, observing, and executing actions all share the same motor representations (Barsalou, 1999). Furthermore, the two types of spatial transformation strategies differ in their level of embodiment. Object-based transformations rely on object-centered representations, whereas egocentric perspective transformations rely on simulated movements of the own body, where proprioceptive information is more relevant (Zacks & Michelon, 2005). It must be noted that Zacks and Michelon (2005) additionally identified a third type of transformation, the environmental reference frame. However, this reference frame is not relevant to the paradigm of mental rotation and is therefore not included in the detailed explanations provided herein.

Motivated by this theoretical framework, the aim of the present thesis is to systematically investigate the influence of different body postures, and thus, the challenges to dynamic stability, on participants' performance in two different mental body-rotation tasks. To achieve this aim, four experiments that gradually increased the challenges to balance control were conducted. Experiment 1 (see Chapter 3.1) examined the difference in mental rotation performance between sitting and standing postures, while Experiment 2 (see Chapter 3.2) focused on the difference between standing and balancing on a balance beam. In Experiment 3 (see Chapter 3.3), the mental rotation tasks were performed while standing on even ground and balancing on a balance board. In Experiment 4 (see Chapter 3.3), the participants stood on a vibrating plate that moved at varying speeds in the medial-lateral direction.

2 Theoretical Background

This chapter discusses the basics of embodied cognition theory, which serves as the theoretical framework for the studies conducted. Additionally, it presents cognitive and spatial abilities, with a focus on the mental rotation ability. The basic mechanisms of postural control are also described, as the research project aims to explore a possible interaction between the performance in mental rotation tasks and dynamic stability.

2.1 Embodied Cognition

> *To say that cognition is embodied means that it arises from bodily interactions with the world. From this point of view, cognition depends on the kinds of experiences that come from having a body with particular perceptual and motor capabilities that are inseparably linked and that together from the matrix within which reasoning, memory, emotion, language, and all other aspects of mental life are meshed* (Thelen et al., 2001, p.1).

Thelen and colleagues' quote demonstrates that embodied cognition involves an interaction between cognition, perception, and movement. The embodiment theory explores this interaction, and there are multiple approaches to explain it. Traditional cognitive theories assume that our brain is only an abstract information processor (e.g. Collins & Quillian, 1969; Kintsch, 1988; Newell & Simon, 1972). However, newer approaches indicate that the representation of objects and events are closely related to the opportunities for action associated with them (e.g. Barsalou, 1999; Garbarini & Adenzato, 2004; Glenberg, 1997; Niedenthal et al., 2005; Wilson, 2002; Zwaan, 1999). How these objects and events are represented in the environment depends on one’s own possibility to act (e.g., Beilock & Hohmann, 2010). One theory, which addresses this phenomenon, is the embodied cognition theory (e.g. Barsalou, 1999; Wilson, 2002). In contrast to classic cognitive theories (e.g. Collins & Quillian, 1969; Kintsch, 1988; Newell & Simon, 1972), which view the brain as the central instance of mental representation and cognition, embodiment research assumes that cognitive processes are not independent of perception and action but interfere with each other (e.g., Raab & Raab, 2022). Although embodiment research is a relatively young field, the idea of a holistic understanding of cognition, perception, and movement is not new. This emphasis of a holistic understanding can be primarily attributed to phenomenology representatives, such as Merleau-Ponty (1945) (e.g., Löffler et al., 2020). Their central idea was to eliminate the dichotomous division between the soul and the body and instead concentrate on the body and its perception. Today's embodied cognition approaches share the central assumption that cognition, perception, and movement processes are interdependent and mutually influence each other (e.g. Barsalou, 1999; Wilson, 2002). This idea is reflected in the basic principles of embodied cognition (e.g., Löffler et al., 2020). In addition to this central commonality, there are different explanations between the various embodied cognition approaches. Shapiro (2019), for example, identifies three different perspectives regarding the role of the body. The first perspective, called *conceptualization*, suggests that an individual's understanding of the world is influenced by the shape of their body. This means that different bodies can lead to different conceptualizations and perceptions of the world. The formation and understanding of these concepts are largely dependent on how an individual moves through the world with their body. The specific characteristics of a body determine the emergence of concepts. The second perspective is known as *replacement*. This means that while the brain still plays an important role, it is no longer the sole determining factor and is instead viewed as an equal partner to the body and the environment. The third and final perspective is termed *constitution*, which posits that cognition encompasses the body. According to this perspective, cognition is not only influenced by the body and the environment, but the body, its movement, and the environment are integral components of cognition (Shapiro, 2019). In summary, the assessment of mental processes should include the body, its movements, and its environment.

2.1.1 Six Points of View of Embodied Cognition

According to Wilson (2002), "*cognitive processes are deeply rooted in the body's interactions with the world*" (Wilson, 2002, p. 625). In her theorizing, she distinguishes six different claims of embodied cognition. First, it is stated that cognitive activity involves perception and action and occurs in the context of the real environment, meaning that cognition is situated. Thus, during the execution of a cognitive process, additional information is perceived that influences processing. Moreover, motor activities are carried out that influence the task-related environment (e.g., Wilson, 2002). Second, cognition is time pressured, meaning that its function must be understood under pressures of real-time environmental interactions. The third claim refers to the limitations of the human's information-processing abilities. To reduce the cognitive workload, one off-loads this cognitive work onto the environment and only collects information on a need-to-know basis. This is especially important for on-line tasks. Here, people can either benefit from prior learned representations or, in case of a novel stimuli or task, reduce the cognitive workload by making use of the environment. To reduce the cognitive work to be done, one leaves the information out in the environment and only accesses to it if necessary (e.g., Wilson, 2002). This information flow between the cognitive mind and the environment leads to the fourth claim, emphasizing that the environment is part of the cognitive system. Cognition in this case includes not only the mind, but also the entire situation and can therefore be designated as an activity including the mind, the body, and the environment. The fifth claim is derived from research in perception and memory and states that the function of cognition is for action. Traditionally, it was assumed that the visual system builds up an internal representation of the world and that the connections between cognition and action are quite direct. However, there must be a more indirect and flexible connection and with this adaptive cognitive strategy, individuals can store information about the environment for future activities without knowing exactly how these activities would look like and are therefore flexible in problem solving (e.g., Wilson, 2002). The sixth claim states that off-line cognition is body based. Thus, even when the activity is not obviously coupled with the environment, the activity of the mind is based on mechanisms of sensory processing and motor control that are evolved for interaction with the environment. There are several examples for this off-line aspect of embodied cognition: Mental imagery including visual, auditory, and kinesthetic imagery is a first example where external events are mentally simulated. There is evidence for a close connection between this imagery and the mechanisms of common perception. A second example for the off-line use of sensorimotor resources are short-term memory (working memory) and long-term memory (episodic memory). Contrary to the point discussed earlier, the information is not off-loaded into the environment but onto perceptual and motor control systems in the brain. In addition, implicit memory can be seen as an embodied way of solving problems confronting the situated preceptor off-line. Automatization plays an important role in this context. New skills are automated through practice, which can be thought of as building up internal representations of a situation and this reduces the cognitive load. The final example is reasoning and problem-solving. In general, spatial mental models improve problem-solving and there are a variety of ways where sensory and motoric resources are used for off-line cognitive activities. Off-line embodied cognition is a widespread phenomenon in the human mind and can be seen as an underlying principle of cognition. To conclude, the six views of embodied cognition distinguish between on-line and off-line aspects. In terms of on-line aspects, cognitive activity is embedded in a task-relevant external situation. Information or cognitive work can be time pressured and off-loaded onto the environment. In contrast, when talking about off-line aspects of embodied cognition, there is only a symbolic off-loading, meaning that external resources are used to help in the mental representation of actions that are distant in time and space (e.g., Schütz-Bosbach & Prinz, 2007; Wilson, 2002).

2.1.2 Mechanisms Explaining the Embodiment Effects

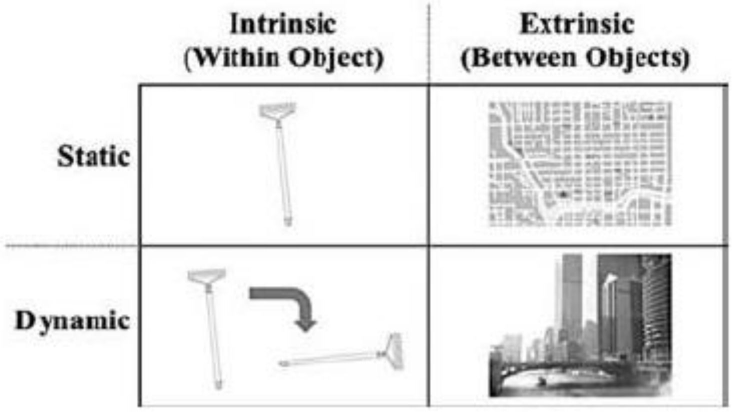
Körner and colleagues (2015) postulate three psychological mechanisms explaining the embodiment effects: state induction, modal priming, and sensorimotor simulation. In state induction, the process of information processing is relevant and not the content of information. Here, movements, actions or external sensations have a direct influence on the psychological state and the information processing. In contrast, when talking about modal priming not the information processing changes but the information content. Behavior is influenced by a concept that can be semantically associated with a physical state (e.g., Raab & Raab, 2022). The fact that the perception of a stimulus automatically leads to interaction simulation with this stimulus is described by the third mechanism, sensorimotor simulation (e.g., Barsalou, 1999, 2008). Therefore, it is easier to perform actions that are congruent with the simulation than actions that are incongruent. These mechanisms refer to so called on-line effects. Besides this, there are also off-line effects when embodiment theories are categorized in the context of cognition and motor skills. This distinction between on-line and off-line effects is also made by Schütz-Bosbach and Prinz (2007). In ancient theories of social cognition, it is postulated that there must be a certain understanding of action to imitate the actions of others. However, Schütz-Bosbach and Prinz (2007) argue that this assumption is too short-sighted and incomplete, as it neglects the perspective of the actor. In their opinion, it is rather the case that actions modulate perception and that a distinction can be made between on-line and off-line effects. In cases of on-line effects, observers may be less sensitive (contrast effects) or more sensitive (assimilation effects) to visual stimuli such as their own activity. Contrast effects can be described by "*action-induced blindness*" (Schütz-Bosbach & Prinz, 2007, p. 350), meaning that actions increase perceptual sensitivity to events that do not correspond to what a person is currently doing. In contrast, when talking about assimilation effects, actions increase perceptual sensitivity to events that have similar characteristics to what a person is currently doing. Current actions can therefore sometimes increase and sometimes reduce the sensitivity of perception (Schütz-Bosbach & Prinz, 2007). On the other site, situations in which action-related processes are temporally separated from the relevant perceptual processing are referred to as off-line effects of motor action on perception. Several studies investigated these effects and found different influences: First, the preparation for an action can increase perceptual sensitivity to events that are directly linked to the motor specifications of that action (influence of motor intention). Second, the recognition performance of the observed action can be directly or selectively influenced by motor learning (influence of motor learning). The influence of motor competencies means, that knowledge of movement characteristics can influence visual coding. Third, motor expertise can also have an influence. Experts show a specific perceptual sensitivity for actions that fall within their individual area of expertise. To sum up, action and perception cannot be considered separately but influence each other in a way that the knowledge of an action can determine what is currently perceived and otherwise just perceiving an event can activate a related action. The relationship between action and perception can therefore be described as follows: On the one hand, perception influences action (as signified by *motor resonance* phenomena), but on the other hand, action can also influence perception (as signified by *perceptual resonance* phenomena) (Schütz-Bosbach & Prinz, 2007).

2.2 Cognitive and Spatial Abilities

A superordinate theoretical framework to contextualize the cognitive process of mental rotation are the theories of cognitive abilities and spatial abilities. According to Carroll (1993), a cognitive ability "*is any ability that concerns some class of cognitive tasks*" (p. 10). An ability, in this context, refers to the successful completion of a quantifiable task at a specific threshold for an individual, allowing for the measurement of inter-individual differences in abilities. A cognitive task is defined as "*any task in which correct or appropriate processing of mental information is critical to successful performance*" (Carroll, 1993, p. 10). Mental rotation tasks fall within these definitions since participants are not permitted to use any resources (such as to adjust their own head position to the rotated stimuli) other than cognitive operations to overcome the spatial disparity problem. Mental rotation falls under the category of spatial abilities (e.g., Linn & Petersen, 1985; McGee, 1979; Uttal et al., 2013). There are various approaches to define and measure spatial abilities. In his 1979 article, McGee conducted a review of factor analytic studies on intelligence and ability tests. He identified two factors that were intended to represent spatial abilities: visualization and orientation. The visualization term was described as the ability to "*mentally manipulate, rotate, twist, or invert a pictorially presented stimulus object*" (McGee, 1979, p. 893), whereas the orientation factor constitutes the ability to comprehend "*the arrangement of elements within a visual stimulus pattern*" (p. 893). Linn and Peterson (1985) classified spatial abilities into three categories by separating mental rotation from visualization: (1) spatial perception (like the orientation factor mentioned by McGee, 1979), (2) mental rotation, and (3) spatial visualization. However, the reviewed articles in both meta-analyses considered tests that do not refer to one specific theory but to various categorizations of spatial abilities. This leads to a factor structure in which one factor probably represents various abilities containing some common features, but there is no clear definition of what these common features are. In a more recent theory, Uttal et al. (2013) and Newcombe & Shipley (2015) attempted to address the persistent issue of deducing factors from different tests that refer to different categorizations of spatial abilities (Linn & Petersen, 1985; McGee, 1979) by introducing a categorization in which most common test items can be assigned unambiguously. The theory consists of a two-by-two matrix with differentiating intrinsic vs extrinsic visual information and static versus dynamic tasks (see Figure 1). *Intrinsic visual information* refers to the spatial properties of an object (i.e., the shape and parts that make up an object and their relative positions to each other), whereas *extrinsic visual information* refers to the location of the object relative to other objects and the environment in general. Task demands can be classified as either static or dynamic. *Static tasks* require an analysis of stable spatial relations, while *dynamic tasks* require an analysis of changing spatial relations (Uttal et al., 2013; Newcombe & Shipley, 2015).

Figure 1

A 2x2 classification of spatial skills by Uttal et al. (2013, p. 354).



Note: Examples of each spatial process. Left panel: intrinsic visual information for static (above line) and dynamic (bottom line) tasks; Right panel: extrinsic visual information for static (above line) and dynamic (bottom line) tasks.

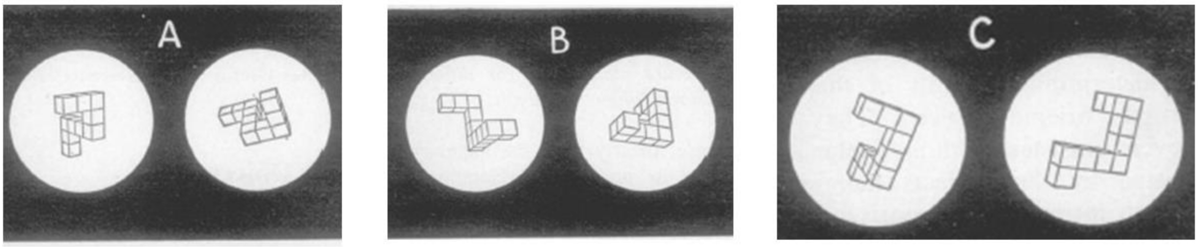
This categorization yields four possible spatial tasks: Intrinsic static tasks that require analyzing object information (e.g., identification of objects as members of categories, including their size and configuration). These tasks can be viewed as a straightforward recognition or retrieval process that facilitates object identification. Intrinsic dynamic tasks require a mental transformation of objects, such as rearranging object pieces (e.g., imagining a person moving different body parts) or performing a rigid mental rotation (e.g., imagining an object rotating in empty space). Extrinsic static tasks require analyzing non-moving objects and their relationships to each other (e.g., map reading or estimating distances between objects). Extrinsic dynamic tasks involve analyzing the movement of objects and their spatial relations to one another. This type of task is common in team sports, where it is necessary to analyze the varying positions and routes of players relative to one's own position, teammates, or opponents. Navigation through a city is another example of an extrinsic dynamic task, as it requires a constant update of one's own position relative to the environment, including other moving objects, such as cars or pedestrians (e.g., Uttal et al., 2013; Newcombe & Shipley, 2015). Therefore, when considering the framework of spatial abilities, a mental rotation task can be classified as an intrinsic dynamic task.

2.3 Mental Rotation

The mental rotation task (MRT) is a widely used paradigm in cognitive psychology. It was first introduced by Shepard and Metzler (1971) and examines peoples' "ability *to spatially transform two-dimensional or three-dimensional objects or bodies from one orientation in mental space to another*" (Steggemann-Weinrich & Weigelt, 2019, p. 173). In the classic chronometric MRT, two images of three-dimensional objects are shown side-by-side (see Figure 2). The left picture serves as a reference frame and is presented in an upright position, whereas the right picture is rotated in the picture plane at different rotation angles. Participants are asked to view these two images and decide whether these two images presented display the same or different objects.

Figure 2

Examples of the classic chronometric MRT by Shepard & Metzler (1971, p. 702).



Note: (A) A "same" pair, differing in the picture plane by an 80° rotation; (B) a "same" pair, differing in depth by an 80° rotation; (C) a "different" pair, which cannot be brought into congruence.

Reaction times, error rates, and mental rotation speed can be defined as independent variables. The typical pattern of results shows that these variables increase with increasing angular disparity (Shepard & Metzler, 1971). This pattern of results supports a linear relationship between reaction time and angular disparity. The linearity of the function is evident for rotation in picture plane as well as for rotation in depth plane (Shepard & Metzler, 1971). Concerning Cooper and Shepard (1973), the slope and the intercept of the function line refer to four different sequential cognitive processes: (1) stimulus encoding, (2) mental rotation, (3) comparison of objects, and (4) motoric reactions. The authors propose that this pattern indicates a similarity between the mental rotation process and the process of manual movement (Cooper & Shepard, 1973). This assumption is also supported by Wohlschläger and Wohlschläger (1998), who argued that mentally rotating an object is in somehow like a manual (physical) rotation because there is a common process controlling the rotation in both cases: This control process initiates a change in the visual-spatial representation during mental object rotation and is responsible for motor commands during manual rotation. The authors named this a "common-processing hypothesis", implying two things: First, both tasks should depend on each other, and second, task constraints have the same effect on mental rotation as on actual rotation (Wohlschläger & Wohlschläger, 1998).

The relationship between mental rotation and manual rotation is also visible at a neurophysiological level. Imaging techniques have shown the involvement of different brain areas while performing a mental rotation task. The parietal cortex, the frontal lobe, and the primary motor cortex appear to be of particular importance in mental rotation processes (e.g., Cohen et al., 1996; Kosslyn et al., 1998; Zacks, 2008). The mental rotation process in general is associated with the activation of the intraparietal sulcus and adjacent regions. The greater the angular disparity between the two stimuli presented, the greater the activity in this region of the brain (e.g., Culham & Kanwisher, 2001; Gogos et al., 2010). According to Zacks (2008), this supports the notion that mental rotation depends on analog representations because activity in these brain areas is modulated by manipulations of mental rotation tasks. Moreover, if the focus of the conditions is on motor simulation, increased activity in the medial superior precentral cortex can be seen. This supports the notion that in some situations there is an involvement of motor processes in mental rotation (Zacks, 2008).

There are two different approaches to test for mental rotation abilities, a psychometric testing approach (computer-based approach) and a chronometric approach, respectively. Methodologically, the chronometric approach is based on a paper-and-pencil version of the mental rotation test, developed by Vandenberg and Kuse (1978). The test was constructed from the figures used in the study of Shepard and Metzler (1971) and has been used in many different versions, like for example with cube figures, spanish adaption of solid figures, or purdue visualization of rotation test (for a meta-analysis see Voyer, 2011). However, the chronometric approach is not within the focus of this dissertation and will therefore not be further addressed in detail.

In general, the performance in a mental rotation task can be influenced by different factors and their interaction. This could be, for example, the age and gender of participants, different stimuli, or the use of different mental rotation strategies.

2.3.1 Influence of Age and Gender

The most common mental rotation task, as assessed by paper-and-pencil tests, typically yields better performance by men than by women. This gender difference in performance on paper-and-pencil tests of mental rotation is well documented, as evidenced for example by the findings of Hedges and Nowell (1995), Linn and Petersen (1985), and Voyer and colleagues (1995). A multitude of explanations have been proposed to account for these gender differences (see Halpern, 2000). One potential factor contributing to the observed gender differences in mental rotation is the influence of time limitations. In a study conducted by Goldstein and colleagues (1990), the MRT was administered under standard timed conditions. It was observed that men demonstrated a higher performance than women. The gender difference was eliminated when an un-timed condition was used. Goldstein and colleagues (1990) posited that women tend to work more slowly and carefully when completing a mental rotation task, whereas men are more likely to guess and work faster. Accordingly, the authors posited that these performance factors could account for the observed gender differences in mental rotations and postulated that gender-related discrepancies in mental rotation should be less pronounced when subjects are allotted an unrestricted period to complete the task. The experimental data supported this hypothesis as the previously identified gender differences became insignificant on the Vandenberg and Kuse Mental Rotation Test (1978) in the absence of time limitations (Goldstein et al., 1990). Nevertheless, contrary findings were reported by other researchers. For example, Masters (1998) manipulated time limits and demonstrated that gender differences in MRT performance were slightly but not statistically significantly greater in the absence of time limits. Further evidence can be found in the works of Voyer and Sullivan (2003) and Delgado and Prieto (1996). In addition, Voyer (2011) conducted a meta-analysis to examine the hypothesis that time constraints affect the magnitude of gender differences in paper-and-pencil tests of mental rotation. The aim was to quantify the influence of time constraints on gender differences in such tests. The results demonstrated that gender differences in mental rotation are considerably more pronounced when the task is administered with time constraints, regardless of their duration, in comparison to when such constraints are absent. Moreover, the magnitude of the gender differences was found to be linearly related to the amount of time available for test completion. The findings were not influenced by the age or year of birth of the participants in the retrieved studies (Voyer, 2011). By contrast, studies utilizing chronometric methodologies often failed to consider the influence of gender on the observed phenomena. In a study published in 2007 by Jansen-Osmann and Heil, the authors investigated gender differences in the context of stimulus material, with a particular focus on polygons. The findings revealed a significant, reliable gender effect in mental rotation, with males demonstrating a greater performance advantage. With respect to age-related effects, empirical evidence indicates that mental rotation performance, as well as various measures of cognitive functioning (for a review, see Blanchard-Fields & Hess, 1996), tends to decline with age (e.g., Cerella et al., 1981; Lord & Marsh, 1975). Some studies have attempted to explain the performance of the elderly in a mental rotation task. Hertzog and Rypma (1991) proposed that the observed decline in mental rotation performance among older adults might be attributed to the age-related decline in spatial working memory capacity, particularly when rotational transformations are required. In contrast, Dror and colleagues (2005) proposed that the inferior performance of the elderly is attributable to the utilization of a holistic strategy: Whereas younger individuals tend to employ a piecemeal rotation approach, older adults tend to mentally rotate the entire object. The primary objective of the study conducted by Jansen and Heil (2009) was to examine the potential for gender-specific differences in mental rotation abilities among younger (ages 20-30), middle-aged (ages 40-50), and older (ages 60-70) adults. The study employed a psychometric approach (MRT) and a chronometric approach based on polygons to assess these differences. In accordance with previous research (e.g. Meinz & Salthouse, 1998) on cognitive functions, mental rotation performance demonstrated an inverse relationship with increased age, regardless of the measurement approach employed. This included the paper-and-pencil MRT and the chronometric task. Moreover, males consistently demonstrate superior performance to females across all age groups. In conclusion, it can be stated that gender-related differences in mental rotation abilities remain consistent throughout the aging process.

Regarding children performing a mental rotation task, Frick and colleagues (2013) for example posit that there is a considerable development in mental rotation between the ages of three and five. To assess for mental rotation abilities, they used a puzzle paradigm, a task that is comparable to the ones used with older children and adults. Children were presented pairs of asymmetrical ghost figures (three-dimensional cut-outs or two-dimensional paper versions) in seven orientations and were required to determine whether the ghost fit into a hole or whether it was a mirror image and would not fit. The results demonstrated a developmental trend, with a notable improvement in mental rotation abilities observed between the ages of three and five years. Additionally, the tasks yielded no consistent performance differences in favor of either boys or girls (Frick et al., 2013).

2.3.2 Previous Studies and Stimuli in the Context of Mental Rotation

Besides the classical mental rotation task, previous studies used a variety of different stimuli to examine the mental rotation skills using the psychometric testing approach. For example, the mental rotation of two-dimensional objects (e.g., Cooper, 1975), alphanumeric characters (e.g., Cooper & Shepard, 1973), images of human body parts (e.g., Bläsing et. al., 2013), or whole human bodies (e.g., Amorim et al., 2006; Kaltner & Jansen, 2016; Pietsch & Jansen, 2018). The typical pattern of results in all these studies shows that response times and response errors increase linear with increasing angular disparity, signifying the cognitive effort required to transform the objects in mental space. Thus, the findings for the standard mental rotation task have been generalized to a variety of different stimuli. However, the type of stimuli has an influence on mental rotation performance. For instance, in order to introduce embodied cognition into mental rotation tasks, researchers have employed the use of body parts or whole human bodies as stimuli. (e.g., Amorim et al., 2006; Voyer & Jansen, 2016). Previous studies have already shown that there is a relationship between body-part stimuli, mental rotation, and the body (e.g., Amorim et al., 2006; Voyer & Jansen, 2016). Parsons (1987a, 1994), for example, showed that it is easier to mentally rotate a picture of a biomechanically comfortable hand rotation than a picture of an uncomfortable hand rotation. The study provides evidence that the mental rotation of images of body parts correlates with the time it takes participants to imagine the corresponding action of the body part. The author's conclusion is that the subjects' strategy was to imagine their own hand as a comparison for the rotated stimulus (Parson, 1987a, 1994). Supporting this notion, Amorim and colleagues (2006) showed that adding a human head to a classic cube figure improves mental rotation performance. This is due to the fact that one's own body axis is mapped onto the axis of the rotated stimulus. In addition, the importance of the stimulus material has also been demonstrated in a study with positron emission tomography (PET) by Kosslyn and colleagues (1998). The results of their study showed that only the mental rotation of the hands activated brain regions associated with low-level motor processes, indicating that the hand stimuli were mentally rotated differently than the cube stimuli. This research shows that stimulus type matters and, for example, using human bodies or body parts as stimuli is applied within an embodied cognition framework.

2.3.3 Object-based and Egocentric Transformation Strategies

In general, three types of mental transformations can be distinguished: These are performed according to (1) an environmental reference frame, (2) an egocentric reference frame, and (3) an object-based reference frame (Zacks & Michelon, 2005; Zacks et al., 2000). The environmental reference frame is defined relative to a fixed point in the environment. In this context, things are located relative to axes with respect to a fixed space. While this type of mental transformation is not of further relevance for the present dissertation, the other two reference frames are in the focus of interest. According to Zacks and Michelon (2005), the egocentric reference frame is defined relative to the self. People use this strategy with the axes up-down, front-back, and left-right. The third type of reference frame, the object-based reference frame, is defined relative to external objects and can be used for characterizing the relationship between parts of an object independent of the object's location in the environment. It can be also used to locate an object relative to another one (Zacks & Michelon, 2005; Zacks et al., 2000). In an object-based mental rotation task, the position of the observer remains unchanged, and the stimulus is mentally rotated in relation to the environment. In an egocentric transformation task, a person must change their own perspective and put themselves in the stimulus position (e.g., Kessler & Rutherford, 2010). There are different ways inducing these transformation types: Amorim and colleagues (2006), for example, conducted a series of object-based mental rotation task and point out that the type of stimulus material is crucial. The results of their study postulate, that embodied stimulus material leads to better performance. According to the authors, this is due to the stimulation of motor processes (Amorim et al., 2006). Steggemann and colleagues (2011) argue that the type of decision that needs to be made in the task has an influence on which type of transformation is chosen. In an egocentric transformation task, the stimulus material is often a human body presented with either the left or the right arm outstretched. In these types of tasks, the participants must decide about laterality, namely whether the left or the right arm is outstretched. In contrast, in an object-based transformation task, participants must decide whether the two stimuli presented are the same stimuli or whether one stimulus is a mirrored version of the comparison stimulus (Steggemann et al., 2011).

Interestingly, according to Kessler and Thomson (2010), egocentric and object-based mental rotation tasks are embodied differently. In a series of four experiments, these authors contrasted a variety of accounts in terms of the assumed processes and the nature of embodiment. The goal of their study was to determine whether the spatial perspective is a function of motor embodiment. The results showed evidence that transformations during spatial perspective taking comprises a large part of the body schema, which was not found for object-based rotation. Thus, the studies provide evidence for different embodiment patterns for spatial perspective taking and object-based rotation. According to the authors, the embodiment of spatial perspective taking is related to self-initiated imitation of a body movement and supports the notion of endogenous motoric embodiment. Furthermore, the results show that the motoric embodiment effects occur at higher angular disparities and depend on whether mental rotation processes are actually used to solve the task. To summarize, the authors conclude that only spatial perspective taking is related to whole body representations (Kessler & Thomson, 2010).

2.4 Postural Control

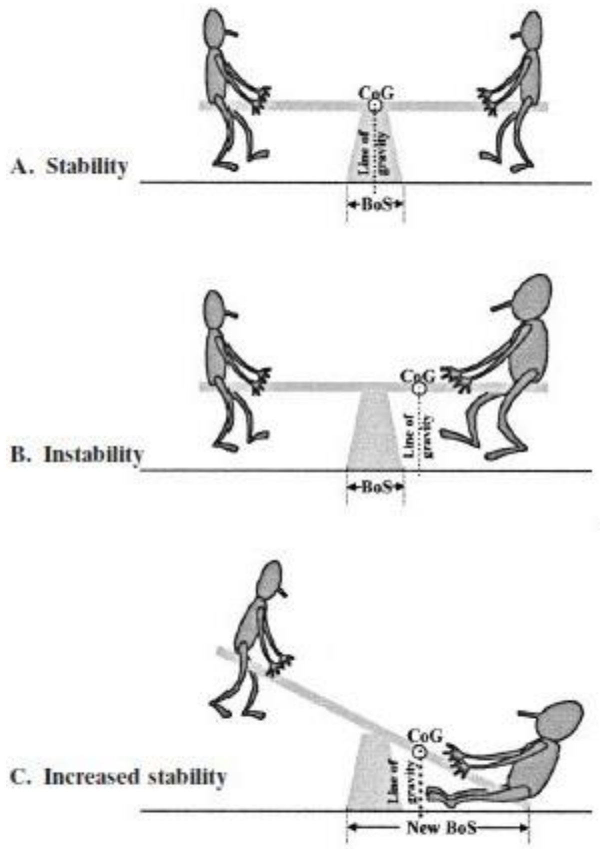
The following chapter defines posture, balance, and postural control. Additionally, it provides a brief overview of the various postural control strategies, and the different types of measurements used to assess postural control.

2.4.1 Definition

Running, walking, and even standing place high demands on the balance control system. Winter (1995) distinguishes in this context between the terms “posture” and “balance”. The term “balance” is frequently employed to describe a multitude of positions and is often used in conjunction with “stability” or “postural control”. Although there is no universally accepted definition, it is helpful to distinguish between these terms. Posture is the “*orientation of any body segment relative to the gravitational vector*” (Winter, 1995, p. 194), whereas balance describes the “*dynamics of body posture to prevent falling*” (Winter, 1995, p. 194). Balasubramaniam and Wing (2002) define posture “*as the geometric relation between two or more body segments*” (p. 531). The maintenance of the relationship between two or more body segments and the entire body in relation to the environment must be actively sustained. Balance in this context refers to the equilibrium that arises from a torque alignment that occurs either before or in response to a postural disturbance (e.g., Balasubramaniam & Wing, 2002). According to Pollock and colleagues (2000), the term balance is defined as “*the state of an object when the resultant load actions acting upon it are zero*” (Pollock et al., 2000, p. 402). Another terminology that is often used synonymously with the term “balance” is “postural stability”, describing the ability of controlling the bodies Center of Gravity (CoG) in relation to the contact surface. The relationship between the base of support (BoS), the line of gravity and stability can be seen in Figure 3.

Figure 3

Relationship between BoS, line of gravity and stability by Pollock et al. (2000, p. 403).



Note: In A the line of gravity falls in the BoS and the object is balanced. In B the line of gravity falls out of the BoS, the CoG moves toward the "heavier" end of the seesaw and the object is unbalanced. In C the object has moved to regain balance and the line of gravity falls in the new BoS.

In a static situation, an object is considered balanced if its CoG is within the support surface. Therefore, balance is dependent on both the support surface and the object's Center of Mass (CoM) / CoG. In this context, stability occurs when the object is in equilibrium, meaning that the line of gravity is within the support surface. Greater surface area results in increased stability. As soon as the line of gravity extends beyond the support surface, the object becomes unbalanced Pollock et al., 2000). The relationship between stability, support surface, and the line of gravity applies not only to objects but also to human balance, such as when standing. Unlike objects, people can independently control their balance and avoid falling for example. Pollock et al. (2000) refer to this as postural control. According to the authors, postural control can be identified by three categories: a specific posture (like standing or sitting), voluntary movement (e.g., between postures) and, a response to an external disturbance (e.g., a trip, a slip, or a push). Postural control is therefore defined as the "*act of maintaining, achieving or restoring a state of balance during any posture or activity*" (Pollock et al., 2000, p. 404).

When talking about balance control and posture, three sensory systems are involved. The primary system is the visual one, whose task is to plan movements and to recognize and avoid obstacles on the way. The second and major system involved is the vestibular system, which perceives both linear and angular acceleration. The third is the somatosensory system. Here, different sensors record the position and velocity of body segments and their contact with external objects as well as the orientation of gravity (e.g., Winter, 1995).

2.4.2 Postural Control Strategies

Traditionally, balance strategies were often viewed as automatic reflexes (e.g., Magnus, 1924; Rademaker, 1935). However, it is now understood that balance is dependent on various variables controlled by the central nervous system (e.g., Horak et al., 1997). There are two strategies used to maintain balance: the ankle strategy and the hip strategy (e.g. Balasubramaniam & Wing, 2002; Winter, 1995). In general, the ankle strategy predicts that the ankle plantarflexors/dorsiflexors ensure alone that the movement is balanced. It is used when standing still and when the perturbation is minimal, and the support surface is stable. Conversely, the hip strategy is employed when the ankle muscles cannot react anymore or when the balance perturbation is rapid and substantial, and the support surface is equal to or smaller than the foot, such as when standing on a balancing beam. In case of larger perturbations, the hip strategy is used. Here, movement is balanced by flexing the hip (e.g., Balasubramaniam & Wing, 2002; Winter, 1995). Additionally, it is important to note that individuals have an alternative strategy for maintaining balance: If the perturbation is too large to be counteracted by standing on the feet, individuals can take a step to regain their balance.

Moreover, the control of balance can be distinguished in a re-active (compensatory) and a predictive (anticipatory) control of balance (e.g. Balasubramaniam & Wing, 2002; Pollock et al., 2000). The re-active control strategy involves a muscular response to an unforeseen disturbance, while the predictive control strategy involves voluntary movement by specifically increasing muscle activity, when a disturbance is anticipated. Perturbations to the balance control system can be either external or internal. Internal perturbations result from voluntary body movements, for example, raising the arm or bending the torso. The response to protect against imbalance in this case is predictive. In contrast, external perturbations occur without the prior knowledge of the individuum. There is a wide range of external perturbations, for example, moving platforms tilting in vertical or horizontal direction or rotating. The response of the sensory system in this case is re-active (e.g., Winter, 1995).

The strategies employed vary depending on the goal and environmental context. Therefore, balance can be considered a fundamental motoric skill that can be learned and improved through practice and training, like other motor skills (e.g. Pollock et al., 2000).

2.4.3 Measurement of Postural Control

A common method for studying postural control is to assess body sway during a quiet, upright stance (e.g., Duarte & Freitas, 2010). This assessment can be either qualitative, conducted through observation, or quantitative, utilizing instruments for measurement. The technique employed to quantify body sway is posturography, which is often divided into two categories: static, which involves studying the individual's quiet, upright stance, and dynamic, which examines the response to external disturbances applied to the individual. The most prevalent posturographic measurement employed in the evaluation of postural control is the Center of Pressure (CoP) (e.g., Duarte & Freitas, 2010). The CoP describes the "*point of location of the vertical ground reaction force vector*" (Winter, 1995, p. 194). For example, when both feet are in a side-by-side position with contact to the ground, the CoP lies somewhere in between the two feet. Moreover, the CoP is independent from the Center of Mass (CoM), a point "*equivalent of the total body mass in the global reference system*" (Winter, 1995, p. 194) and controlled by the balance control system.

To measure postural stability usually the CoP is calculated by using a force plate (e.g., Rhea et al., 2014). A force plate is a device that comprises a board onto which a series of sensors are distributed. These sensors are designed to detect the three force components: F_x, F_y, and F_z and the three components of the moment of force, or torque, acting on this surface: M_x, M_y, and M_z. The x, y, and z axes represent the anterior-posterior (ap), medial-lateral (ml), and vertical orientations, respectively and are used to define the directions of force and moment of force. In consequence, force plates of this type are typically referred to as force plates of six components, given that they measure six physical variables (e.g., Duarte & Freitas, 2010).

The CoP data is related to a measurement of position given by two coordinates on the force plate surface. The CoP position is calculated based on signals obtained from the force plate, which allows for the determination of the position in the ap and ml directions. In order to ensure the optimal acquisition of posturography data, it is essential to observe a number of parameters when utilizing the force plate. These include the frequency of data acquisition, the duration of the data collection period, the number of data points collected, and other pertinent factors. The frequency of data acquisition of the CoP signal is dependent on the task under investigation. In the case of the quiet standing posture, the components of the signal frequency are below 10 Hz (e.g., Winter, 1995). As stated by the Nyquist theorem, the sampling frequency should at least correspond to a double of the frequency bandwidth. Nevertheless, it should be noted that noise may be present at higher frequencies within the signal. Consequently, in everyday practice, acquisition frequencies of up to 100 Hz are typically employed. To analyze the CoP data, it is first necessary to filter the signal, a common procedure in the analysis of biological signals. For the study of a quiet standing posture, a low-pass filter of approximately 10 Hz is sufficient. The choice of filter frequency should be guided by the task parameters and the characteristics of the utilized equipment (e.g., Duarte & Freitas, 2010).

When analyzing the CoP in a quiet stance position, the before mentioned ankle and hip strategies can also be seen. Here, in a side-by-side standing position, the neuromuscular control is a hip strategy in the ml direction and an ankle strategy in the ap direction. When the standing position changes and one foot is placed directly in front of the other, there is a difference in the variation of the CoP amplitude. The fluctuation in the ml direction compared to the fluctuation in ap direction is significantly higher than when the feet are placed in a side-by-side position (e.g. Winter, 1995).

2.4.4 Research on Postural Control

There are several studies and methods for investigating balance. The purpose of some of these studies is to record the motion of body segments, as well as the reaction forces and torques between the feet and the ground. This could be done when external forces act on the joint of interest, perturbing balance, like, for example, by applying forces in a predictable or unpredictable way by the experimenter. In another paradigm, perturbation results from the participants moving, for example, the arm forward (e.g., Balasubramaniam & Wing, 2002).

Research suggests that postural synergies may not be discrete neural synergies, but rather functional synergies that are task-specific, whether spatial or cognitive. Additionally, research shows that there are numerous frequency relationships between ankle and hip movements. The functionality of postural synergies is evident in center of pressure data. The vertical reaction forces in the anterior-posterior and medial-lateral directions can be independently organized, which is necessary in activities, such as archery, where the modulation in the two axial directions differs (e.g., Balasubramaniam & Wing, 2002). Postural synergies are flexible and can be composed based on task parameters that consider biomechanical constraints and attentional factors. The postural control system is strongly connected to systemic environmental changes.

Even though standing seems to be an automatic motor task that requires minimal attention and allows for multitasking, studies on balance control and simultaneously performing a cognitive task have shown that there is an interaction between posture and cognition (e.g., Kerr et al., 1985; Woollacott & Shumway-Cook, 2002). To investigate the interaction between cognition and balance, participants were asked to complete two cognitive tasks, one of which involved high visualization, the other was a non-spatial task. These tasks were completed while standing in a tandem stance (feet behind each other, toe to heel) and while sitting. The studies found no difference in performance between seated positions, but performance on the spatial memory task decreased in the standing position, while there was no decrease in performance on the non-spatial task. The decrease in performance on the spatial memory task in the more difficult balance condition was attributed to limited attentional capacity and competition for limited spatial processing resources. However, the two tasks do not affect stance stability, indicating that maintaining balance is prioritized over spatial processing (e.g., Kerr et al., 1985; Woollacott & Shumway-Cook, 2002). In contrast, there is research, demonstrating that concurrent cognitive tasks do indeed affect the measurement of standing balance. Nonetheless, this seems to be true only for older individuals or those with impairments, not for younger people in normal standing (e.g., Maylor & Wing, 1996; Maylor et al., 2001). All studies suggest that interference between balance and cognitive tasks is due to limited attention, and possibly sensory processes (e.g., Kerr et al., 1985; Maylor et al., 2001; Redfern et al., 2001; Woollacott & Shumway-Cook, 2002). In summary, postural control is adaptable to changing mechanical contexts, as well as visual or tactile changes in the environment. The ability to restore balance or adapt to changing circumstances is highly dependent on the tasks in which one is engaged while maintaining balance (e.g., Balasubramaniam & Wing, 2002).

2.5 Relationship between Mental Rotation, Motor Tasks, and Embodiment

Given that motor and mental rotations are thought to share standardized processes (Wohlschläger & Wohlschläger, 1998) and that mental rotations can be seen as a kind of hidden motor rotation (Wexler et al., 1998), it seems reasonable to link mental rotations, motor tasks, and embodiment. This correlation is also supported by several studies, which examined the relationship between motor expertise and mental rotation skills. For example, people who have expertise in "rotational" sports, such as gymnastics, trampoline, or aero wheel gymnastics, perform better on a mental rotation task than people who have no comparable experience (e.g., Jansen et al., 2012; Pietsch & Jansen, 2012; Steggemann et al., 2011; Voyer & Jansen, 2017). Although mental rotation has been the focus of many empirical studies, one aspect that has received less attention in this context is the relationship between mental rotation and postural control. There are currently a few studies that have examined this relationship. For example, the studies by Kawasaki and colleagues (2013, 2014, 2016) showed that different stimuli (here, different body images) had different effects on mental rotation performance and balance control. In an egocentric task performed in the single-legged position, subjects showed less body sway when they were shown a picture of a foot than when they were shown a picture of a car. This effect could not be shown in the bipedal position. Nor did it hold when the stimulus material showed another part of the body (a hand) (Kawasaki et al., 2014). This effect of mental rotation on balance control in single-leg stance was still present 60 minutes after the intervention, but again more effective for the foot stimulus than for the hand stimulus. As a possible explanation for this pattern of results, the authors suggest that the foot/ankle is more associated with standing than the hand and therefore plays a more important role in controlling balance (Kawasaki & Hinguchi, 2016).

Dault and colleagues (2001) conducted a study to investigate the influence of different working memory tasks (a verbal task, a visuo-spatial task, and a central executive task) on postural control. Participants were asked to perform these working memory tasks, while being confronted with a variety of challenges to postural control (sitting, regular stance, and tandem stance). They examined the effect of an egocentric mental rotation task with stickman as stimuli on the variability of body sway in ap and ml directions. Compared to a control task (observing a fixation cross), but not compared to the other working memory tasks, the results showed a reduction of body sway when performing the mental rotation task (Dault et al., 2001). Similar findings were reported by Hofmann and Jansen (2021). Here, participants stood on a force plate in a narrow two-legged stance and performed two object-based mental rotation tasks (cube vs. human figures), an egocentric mental rotation task with a human figure, a mathematical task (as a cognitive control task), and a neutral task. The results of the study demonstrated a reduction in body sway during an egocentric and an object-based mental rotation task for both embodied and non-embodied stimuli compared to a neutral control task (observing a fixation cross) without any additional task. However, when mental rotation tasks were compared with another cognitive task, such as a math task, there was no difference in body sway. When comparing the two mental rotation tasks, greater body sway with increasing angular disparity was found only for the object-based mental rotation task, but not for the egocentric mental rotation task. In addition, the results of the study showed that embodied stimuli, in this case full-body figures, led to less body sway than the classic cube figures (Hofmann & Jansen, 2021). Another recent study by these authors (Hofmann et al., 2023) showed that in an egocentric mental rotation task, hand and foot stimuli lead to higher body sway than full-body stimuli, and that body sway increases with increasing angular disparity. This increase in body sway with an increase in angular disparity was also true for an object-based rotation task. However, different stimulus types had no effect on body sway in this type of transformation task (Hofmann et al., 2023).

All these studies suggest that there is a relationship between mental rotation, a motor task (e.g., balance control), and embodiment. It seems that mental rotation tasks lead to a stabilization effect compared to control tasks without mental rotation, and that different types of transformation (egocentric vs. object-based) have different effects on balance control.

3 Experiments

The studies aimed to investigate the influence of embodiment effects on the mental rotation of human bodies. A series of four experiments, published in three peer-reviewed manuscripts, systematically changed the position in which participants solved an egocentric and an object-based mental rotation tasks, including sitting vs. standing (Study 1), standing vs. balancing on a beam (Study 2), standing vs. balancing on a balance board (Study 3, Experiment 1) and standing vs. balancing on a vibration plate (Study 3, Experiment 2). In Study 1, it was expected that participants would generally perform better in the egocentric transformation task than in the object-based transformation task (e.g., Kaltner & Jansen, 2018; Kaltner, Riecke, & Jansen, 2014; Pietsch & Jansen, 2018). This would be reflected in faster response times for left-right judgments compared to same-different judgments. It was further hypothesized that the participants' posture during task performance would affect their mental rotation performance. Based on previous studies (e.g., Bray et al., 2004; Kawasaki et al., 2014) the expectation was that performance would improve as the balance requirements increased. Furthermore, the aim of Study 2 was to investigate whether the different demands on dynamic stability are reflected in postural sway parameters. Performing the mental body rotation task was expected to improve postural stability compared to a control condition without mental rotation (e.g. Dault et al., 2001; Hofmann & Jansen, 2021). The third publication (Study 3) examined the relationship between postural control and mental rotation by differentiating between two types of balance control: active balance control (Experiment 1, when standing on a balancing board) and re-active balance control (Experiment 2, when standing on a vibration plate). For the active balance control condition, it was hypothesized that participants would perform better while standing on a balance board (high balance requirements) compared to standing in a parallel position on even ground (low balance requirements) (e.g., Kawasaki et al., 2014). The expectations regarding the effects of re-active balance control were initially unspecific and it was investigated exploratively if vibration intensity (low vs. high) has an impact (positive, negative, or no impact) on mental rotation performance. The studies are briefly described in the following section.

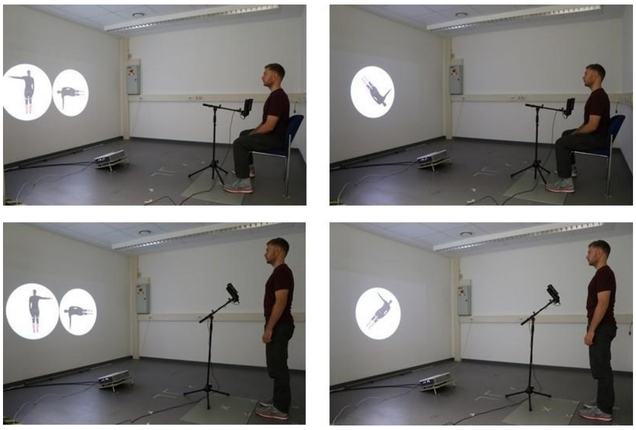
3.1 MBRT in Different Postures: Sitting vs. Standing

The aim of Study 1 (see Budde et al., 2020) was to examine the potential influence of two different postures (sitting vs. standing) when solving mental body rotation tasks with egocentric and object-based transformations. The experiment involved 16 neurologically healthy students (10 males, 6 females). The mean age was 23.5 years. They were not paid for their participation but received course credit. None of them had previously taken part in an experiment involving mental rotation, and all of them gave their written, informed consent.

The experimental session was conducted in the laboratory, where a projector was used to present the stimuli on a bland wall (see Figure 4). Participants viewed the stimuli either while standing upright or while sitting on a chair. A microphone was used to provide verbal responses. There were two different mental rotation tasks, one requiring an object-based spatial transformation and one an egocentric perspective transformation.

Figure 4

Experimental set-up by Budde et al. (2020, p.76).

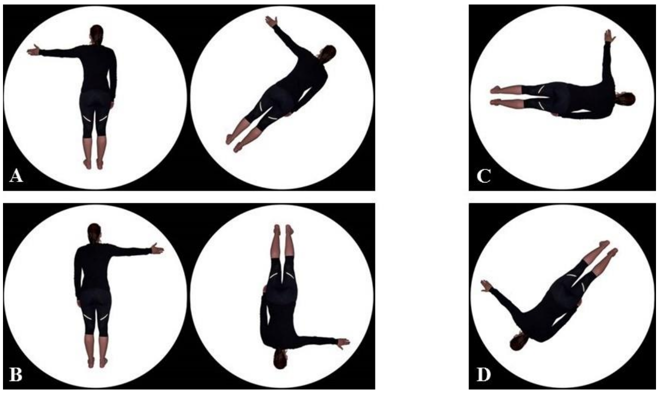


Note: Left panel, the scenario for the object-based transformation task is displayed for the sitting posture (picture on the top) and the standing posture (picture on the bottom). Right panel, the scenario for the egocentric perspective transformation is depicted for the sitting (picture on the top) and the standing posture (picture on the bottom).

In the object-based transformation task (see Figure 5), two images of a female person were presented simultaneously on the screen in back-view perspective, with either the left arm or the right arm outstretched. The experiment presented pairs of images that were either identical or mirror image reversals of each other. The left image in each pair was arranged upright, while the orientation of the right image was randomly rotated in the picture plane (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°). Half of the trials displayed pairs of identical objects, while the other half presented mirror-reversed objects, requiring participants to make a same-different judgment. The participants were asked to quickly and account determine whether the stimulus presented on the right side was identical to the comparison stimulus on the left side. In the object-based transformation task, participants were instructed to respond with “gleich” (German word for “same”), when the stimuli were the same, and with “ungleich” (German word for “different”), when the two stimuli were different. In the egocentric perspective transformation task (see Figure 5), a single image appears on the screen showing a female person with either her left or right arm extended. Therefore, a left or right decision was required. The image showed a person from back view and in a randomly rotated position (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°) within the picture plane. Half of the trials showed the person raising the left arm and half of the trials displayed the person raising the right arm. Participants were asked to quickly and accurately determine whether the person raised her left or right arm. They were instructed to respond with “links” (German word for “left”), when the left arm was raised, and with “rechts” (German word for “right”), when the right arm was raised.

Figure 5

Examples of stimuli by Budde et al. (2020, p.77).



Note: Left panel, object-based transformation task with 45° angular disparity and same pictures (A) and with 180° angular disparity and different pictures (B). Right panel, egocentric transformation task with 90° angular disparity and left arm outstretched (C) and with 225° angular disparity and right arm outstretched (D).

The presentation order of the stimuli was randomized in all conditions. Each trial began with a black screen, followed by a white fixation cross and the stimuli. The stimuli remained on the screen until the participant gave a response. The study protocol involved testing participants in two transformation tasks, namely object-based and egocentric, while adopting two postures, standing and sitting. This resulted in four test blocks. Half of the participants began the object-based transformation task with two blocks, while the other half began the egocentric transformation task with two blocks. They then continued in the opposite condition. The order of sitting and standing postures was balanced for both tasks.

The results of Study 1 showed that participants performed better for egocentric than for object-based transformations, signified by faster response times and fewer error rates. Moreover, the results revealed an effect of orientation with increasing response times from each angular disparity to the next proximate one. The increase of rotation angle had a greater impact on object-based transformation tasks compared to egocentric transformation tasks. However, there was no effect of posture.

In general, the results confirmed the predictions derived from previous studies on mental rotation of human bodies (e.g., Kaltner & Jansen, 2018; Kaltner, Riecke, & Jansen, 2014; Pietsch & Jansen, 2018). Specifically, response time (RT) and response error (RE) increased for visual-spatial transformations of human bodies the more the stimuli had to be mentally rotated. Additionally, participants performed better for egocentric transformations than for object-based transformations. Therefore, aligning oneself with the person displayed is faster than spatially aligning and comparing two objects (e.g., Jola & Mast, 2005; Parsons, 1987a).

However, the study showed that the different dynamics of postural control during sitting and standing do not induce different embodiment effects on mental rotation. Considering the task dynamics in the present study it is possible that the challenge for the dynamics of balance control was not big enough. Therefore, the following studies were conducted to test how participants performed under conditions that were more challenging to balance. Furthermore, it is possible that embodied processes have an influence on the mental rotation of the human body, but they were not detectable in the present experiment. The behavioral measures that were assessed may not have been sensitive enough to detect potential differences between the sitting posture and the standing posture. Examining the dynamics of balance control as postural sway on a force plate may be a more sensitive measure.

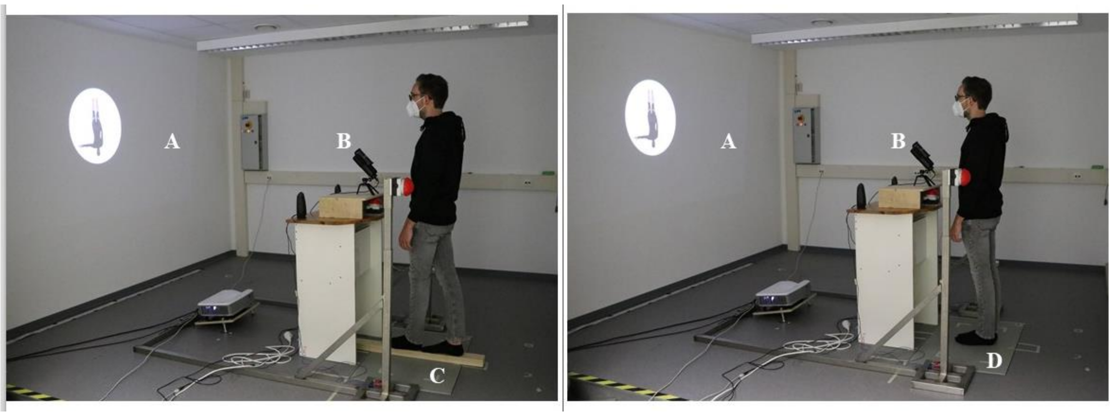
3.2 MBRT in Different Postures: Standing vs. Balancing

The purpose of this study was to investigate the relationship between postural control and mental body rotation. Specifically, the aim was to examine the influence of different demands on dynamic stability for two postures (parallel stand vs. tandem stand, see Figure 6) while solving two versions of the mental body-rotation task. Additionally, it was investigated whether the different demands on dynamic stability were reflected in postural sway parameters. A total of 30 sport science students, consisting of 18 females and 12 males with a mean age of 21.2 years, participated in the current experiment. All participants received course credits but were not compensated for their participation. They self-reported being neurologically healthy and had no prior experience with a comparable mental rotation experiment.

The experimental stimuli were presented on a laboratory wall using a projector. Participants viewed the stimuli while standing either in a tandem stand (one foot behind the other in a heel-to-toe position) on a wooden balance beam or in a feet-parallel position on a force-plate. The stimuli for the object-based transformation task and the egocentric transformation task were identical to those used in Study 1 with an additional control condition, which did not involve a mental rotation task (see Figure 7). Instead, a color-naming task was used, where a yellow or blue circle was presented on a black screen.

Figure 6

Experimental set-up by Budde et al. (2021, p. 183).

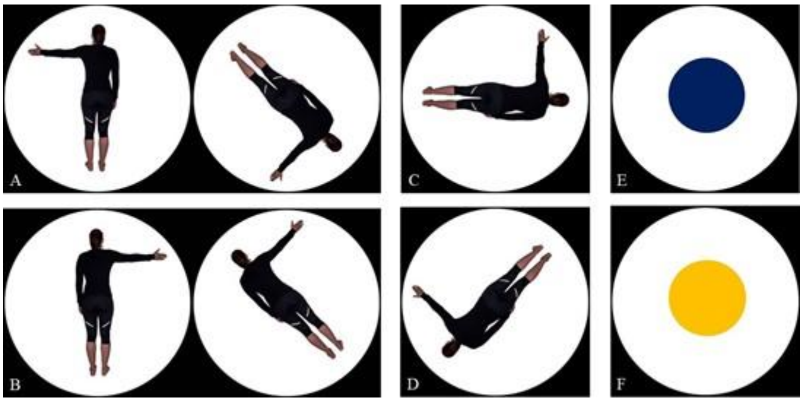


Note: Left picture, tandem stand on a wooden balance beam; right picture, feet-parallel position on a force-plate. (A) the wall on which the stimuli were projected; (B) microphone; (C) balance beam; (D) force plate.

In the control condition task, a single image appears on the screen showing a yellow or blue circle. The participants were instructed to respond with “gelb” (German word for “yellow”), when the yellow circle appeared, and with “blau” (German word for “blue”), when the blue circle appeared. Half of the trials showed a blue circle and half of the trials showed a yellow circle.

Figure 7

Examples of stimuli used in the experiment by Budde et al. (2021, p. 184).



Note: (A) object-based transformation task with 135° angular disparity and different pictures; (B) object-based transformation task with 315° angular disparity and same pictures; (C) egocentric transformation task with 90° angular disparity and left arm outstretched; (D) egocentric transformation task with 225° angular disparity and right arm outstretched; (E) control condition, blue circle; (F) control condition, yellow circle.

The study setup was the same as in Study 1 including two spatial transformation tasks, the object-based transformation task, where participants had to quickly and accurately determine if two simultaneously presented images were the same or different, and the egocentric transformation task, in which participants had to quickly and accurately determine whether the person raised their left or right arm, and an additional control condition of color-identification, resulting in six test blocks. The participant completed all three tasks while standing in a tandem stance on a balance beam and a parallel stance on a force plate. The presentation order of the stimuli was randomized in all conditions and the order of the tasks, and the postures were counterbalanced across the participants.

The results of Study 2 confirmed the results of Study 1 that participants performed better in the egocentric transformation task compared to the object-based transformation task, as reflected by faster response times and fewer errors. This supports the notion that aligning oneself into the person displayed is faster than to spatially align and compare two objects (e.g., Jola & Mast, 2005; Kaltner & Jansen, 2018; Kaltner, Riecke, & Jansen, 2014; Parsons, 1987a; Pietsch & Jansen, 2018; Steggemann et al., 2011). As observed in Study 1, the results also revealed effects of rotation angle. Despite the more challenging balancing task no effect of posture was observed. Therefore, the prediction that participants would perform better while balancing than while standing was not supported. Perhaps embodied processes did not affect the participants' performance because postural control processes do not interfere with perceptual-cognitive processes. The second aim of this study was to investigate whether distinct requirements for dynamic stability are evident in postural sway parameters. Postural control performance was assessed by analyzing the Center of Pressure (CoP) data obtained from the force plate. There was no difference between the mental body-rotation tasks and the control condition, indicating that mental body-rotation task does not seem to affect postural sway parameters. However, the results provide evidence of different levels of stabilization between the two mental body-rotation tasks. Specifically, the egocentric transformation task led to greater postural stability than the object-based transformation task.

3.3 MBRT in Different Postures: Active vs. Re-active Balancing

The present study examines participants' performance in two different mental rotation tasks under conditions in which dynamic stability is challenged in two different balancing conditions: active balance control (Experiment 1) and re-active balance control (Experiment 2), where participants react to an external perturbation.

As in the previous Study 1 and Study 2, the stimuli were presented via a projector on a wall in the laboratory and verbal responses were given using a microphone. The stimulus material for the egocentric transformation task (Experiment 1 and 2), the object-based transformation task (Experiment 1), and the control condition (Experiment 1) was identical to the stimulus material used in the previous studies.

Experiment 1: Active Balance Control

In Experiment 1, 48 sport science students (26 females and 22 males) with a mean age of 22.4 years participated. All participants described themselves as neurologically healthy and none of them had participated in a comparable mental rotation experiment in the previous six months. They received course credit but no financial or other benefit for participating.

Participants completed all three tasks either while standing on even ground with their feet in a narrow parallel position (low balance requirements, see Figure 8) or while standing on a balance board (high balance requirements, see Figure 8), resulting overall in six test blocks. The order of the tasks as well as the order of the postures was counterbalanced across participants.

Figure 8

Experimental set-up of Experiment 1 by Budde & Weigelt (2023, p. 4).

Note: Experimental set-up with the two balancing conditions (left: standing on a balance board; right: parallel stand on even ground). (A) projector; (B) wall on which the stimuli were projected; (C) microphone; (D) balance board.

The results for response times and response errors showed effects of rotation angle and task type. More specifically, response times and response errors increased at higher rotation angles. Performance was also better for egocentric than for object-based spatial transformations. An effect of balancing condition was only observed for response error.

The results are consistent with previous studies of mental rotation. Participants performed better for egocentric perspective transformations than for object-based transformations, which supports the notion that it is faster to align oneself with the displayed person than it is to spatially align and compare two objects (e.g.: Jansen, Lehmann, & van Doren, 2012; Jola & Mast, 2005; Kaltner et al., 2014; Parsons, 1987a; Pietsch & Jansen, 2018; Steggemann et al., 2011). However, the different postural control demands do not seem to influence performance in the mental body rotation tasks, neither for egocentric perspective transformation nor for object-based transformation. It seems that regardless of the difficulty of a cognitive task (with or without mental rotation), manipulating the balance position does not influence performance.

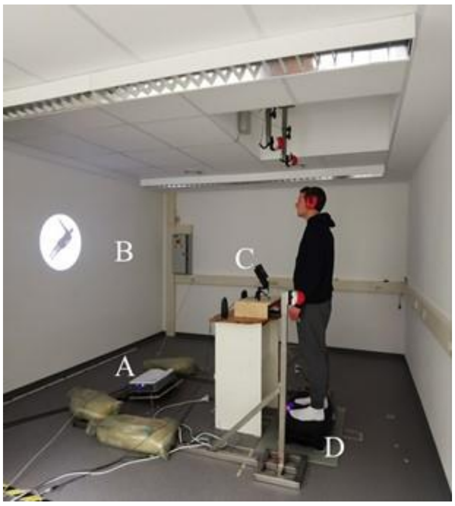
Experiment 2: Re-active Balance Control

The sample size of Experiment 2 consisted of 32 sport science students (12 females and 20 males) with a mean age of 22.1 years. All participants self-reported as neurologically healthy and had not participated in a similar mental rotation experiment within the previous six months. Participants received course credit but did not receive any financial or other benefits for their participation.

In Experiment 2 participants completed only the egocentric transformation task while either standing still on a vibration plate (no vibration) or with the vibration plate moving in a low (20 Hz) or high (180 Hz) frequency. The first block of trials served as a baseline condition (no vibration). Participants performed in this condition without prior experience with different vibration conditions. After performing in the baseline condition, the participants were tested in two additional conditions, one in which the vibration plate was moved at a low frequency (20 Hz) and one in which the vibration plate was moved at a high frequency (180 Hz). The order of the two vibration conditions was counterbalanced across participants.

Figure 9

Experimental set-up of Experiment 2 by Budde & Weigelt (2023, p. 8).



Note: Experimental set-up with the standing position on the vibration plate. (A) projector; (B) wall on which the stimuli were projected; (C) microphone; (D) vibration plate.

The data of this experiment revealed that response times and response errors increased as the rotation angle increased, which is in line with our previous studies (Budde et al., 2020, 2021). However, there was no effect of vibration intensity on participants' performance. The different balance demands do not seem to affect performance in mental rotation tasks with re-active balance control, as well as in previous studies with active balance control (Budde et al., 2020, 2021). Embodied processes do not affect participants' mental rotation performance. There appears to be no interference between postural control processes and mental rotation.

4 Discussion

The purpose of this thesis was to investigate the relationship between postural control, related to maintaining balance, and performance in two mental rotation tasks: an egocentric and an object-based transformation task. The studies aimed to investigate how different postural conditions, and thus challenges to dynamic stability, affect participants' performance in two mental body rotation tasks. Three studies were conducted to gradually increase the challenges to balance control. In all studies, healthy young students performed two mental rotation tasks (MBRTs). One task induced an egocentric perspective transformation (left-right judgment; Study 1-3), and the other induced an object-based transformation (same-different judgment; Study 1-2; Study 3, Experiment 1). Additionally, a color-naming task (blue and yellow circles) without any mental rotation was presented as a control condition in Study 2 and 3 (only Experiment 1). It was hypothesized that performing a same-different judgment task would result in an object-based transformation, while a left-right judgment task for an image of a female person in back view with either the left or right arm outstretched would induce an egocentric perspective transformation in participants. Previous research on mental rotation (Jola & Mast, 2005; Kaltner et al., 2014; Pietsch & Jansen, 2018; Steggemann et al., 2011) suggests that participants perform better in egocentric perspective transformations than in object-based transformations, as reflected in faster response times and fewer response errors. The three studies predicted that challenging dynamic stability in two ways (active balance control in Study 1-3 and re-active balance control in Study 3, Experiment 2) would affect performance in the two MBRTs. Differences in performance across balance conditions were predicted in the MBRTs, with a preference for the balance condition with higher balance demands: standing (Study 1), standing on the balance beam (active balancing, Study 2), and standing on the balance board (active balancing, Study 3, Experiment 1). Furthermore, in Study 3 (Experiment 2), the effects of re-active balance control on mental rotation were examined. The predictions were unclear: either such differences appear in the MBRT with left-right judgment, favoring the higher or the lower intensity, or there are no differences between the balancing conditions.

Consistent with previous studies on mental rotation (e.g., Jola & Mast, 2005; Kaltner et al., 2014; Pietsch & Jansen, 2018; Steggemann et al., 2011), the results indicate that response times and response errors increase as the degree of rotation required for visual-spatial transformations of human bodies increases. The MBRT performance was better for egocentric perspective transformations than for object-based transformations. This was the case in all three studies and supports the idea that it is easier to align oneself with the depicted person than it is to spatially align and compare two images (Jola & Mast, 2005; Parsons, 1987).

The different balancing conditions in which participants solved the MBRTs did not affect their mental rotation performance. Regarding the embodied cognition approach, which posits that mental and motor processes are interconnected (Barsalou, 1999; Wexler, Kosslyn, & Berthoz, 1998; Wilson, 2002), and based on previous studies (e.g., Bray et al., 2004; Kawasaki & Hinguchi, 2016), which found improved performance when postural control was challenged, this result was unexpected. Based on the embodiment approach, it can be assumed that the mental rotation of the body leads to cognitive processes that are used for motor imagery and can therefore interfere with the actual motor tasks (Parsons, 1994; Schwoebel et al., 2001). For example, the study by Kawasaki and Hinguchi (2016) showed reduced postural sway in unipedal standing during an egocentric mental rotation task using an image of a foot as a stimulus. The foot plays a critical role in maintaining balance (Gage et al., 2004), as body parts directly involved in postural control can interfere with postural stability. Thus, one might conclude, that the postural stabilizing effect observed after the egocentric mental rotation of foot stimuli can be transferred to a paradigm examining the effects of simultaneous mental rotation (egocentric and object-based transformation) of the whole body on postural stability. However, the results of all three studies suggest that whole body stimuli do not contribute to postural control. The experimental results consistently indicate that challenges to dynamic stability and balance posture did not affect performance in the MBRTs. In all studies, participants were able to solve the tasks equally well and map their own body representation to the presented figure, regardless of the balance position they were tested in. It is possible that embodied processes had no effect on participants' performance because postural control, such as maintaining balance, does not interfere with perceptual-cognitive processes, such as performing mental body-rotations.

Contrary to the idea that challenging dynamic stability improves performance (e.g., Bray et al., 2004; Kawasaki et al., 2014, 2016), the results indicate that the balancing condition in which participants solved the MBRTs did not affect their mental rotation performance. This is applicable to both the active balancing condition in Studies 1, 2 and 3, Experiment 1 (standing on even ground, standing on a balance beam, standing on a balance board) and the re-active balancing condition in Study 3, Experiment 2 (no vibration vs. low and high vibration). Furthermore, this was also observed in the control condition (Study 2 and Study 3, Experiment 1), where no mental rotation was required. Therefore, it appears that the type of cognitive task, in this case the MBRTs and a color-naming task, performed by the participants is unimportant. Also, the varying balancing conditions (low vs high balancing requirements) did not affect performance in these tasks. This contrasts with the findings by Hofmann and Jansen (2021). While performing the mental rotation task, they found a significant influence on the reduction of postural sway parameters. However, this was only observed when the performance of the participants was compared to a control condition in which they were not required to do anything other than look at a fixation cross. When comparing a math task to a mental rotation task, there was no difference in terms of body sway. This finding is consistent with a study conducted by Dault and colleagues (2001), who also found that a mental rotation task using stick figures resulted in greater postural stability compared to no mental task. However, no significant differences were found between the mental rotation task and other working memory tasks. This suggests that the addition of a task contributes to postural stabilization (Dault et al., 2001; Hofmann & Jansen, 2021, 2023).

Interestingly, the results of Study 2 indicate different levels of stabilization between the two mental body rotation tasks. Specifically, the egocentric transformation task leads to greater postural stability than the object-based transformation task. This is reflected in a reduced range of motion in the anterior-posterior and medial-lateral directions, as well as a lower sway velocity. These findings are consistent with those of Hofman and Jansen (2021), who also observed differences between egocentric and object-based transformation tasks involving cube figures. The results of Study 2, as well as those of Hofmann and colleagues (2021, 2023) indicate, that task difficulty does affect body sway, with increasing difficulty leading to an increase in body sway. In mental rotation tasks, object-based transformation tasks and larger rotation angles typically result in higher response times and error rates, indicating greater difficulty (Hofmann et al., 2023). Pellecchia (2003) also supports this idea by suggesting that more demanding cognitive tasks require more cognitive resources, which leads to a decrease in postural stability. It is suggested that, as a cognitive task becomes more complex, it may require more effort from the explicit system (Hofmann et al., 2023; Pellecchia, 2003). On the other hand, Dault and colleagues (2001) suggest that postural control is not affected by task difficulty, and that postural stabilization depends only on whether a cognitive task is being performed simultaneously. They suggest a co-contraction control strategy of postural muscles in the central nervous system as an alternative explanatory approach, which may result in tighter control of body sway. However, they also note that this strategy is not dependent on task difficulty. As mentioned earlier, since the mental rotation tasks vary in difficulty, this approach cannot be used to interpret the current results. In general, there is conflicting evidence regarding the impact of exercise on cognitive performance (Chang et al., 2012). For instance, Dodwell et al. (2019) found that individuals performed better on a visual working memory task while walking on a treadmill or cycling compared to sitting or standing. There are several explanations for a more stable posture during simultaneous cognitive task performance. One possible explanation is that attention shifts to the simultaneous cognitive task, resulting in more automated processing of the postural task (Donker et al., 2007). However, postural control is generally a highly automated process (Massion, 1992). The quiet upright posture is a simple standing position. It may be somewhat artificial (Wulf et al., 2001) and could potentially interfere with the automated process.

What is surprising are the findings regarding the different perspectives of motor imagery. Stins and colleagues (2015) and Zacks and Michelon (2005) distinguish between kinesthetic viewpoints, where an individual is imagining that he or she is doing an action, and a visual perspective, where an individual is imagining that another person is doing an action. Therefore, a mental body rotation task with embodied stimuli is consistent with the kinesthetic perspective. Solving this type of task is expected to generate more body sway than an object-based transformation task. However, compared to the egocentric transformation task, the object-based transformation task had higher maximum range values in the anterior-posterior and medial-lateral directions, indicating more instability.

Upon closer examination of the influence of angular disparity, it becomes apparent that there is no consistent pattern of results. Hofmann and Jansen (2021, 2023) showed that whole-body stimuli with an object-based transformation strategy resulted in a greater increase in body sway at 180° angular disparity compared to other rotation angles. However, in contrast to the results of Study 2, there was no increase in postural sway with an egocentric transformation strategy. Study 2 revealed a difference in postural sway between the 45° and 135° angles, with greater sway at higher angular disparity. However, at 180°, postural sway was smaller compared to 135°. Hofmann and Jansen (2023) demonstrated greater body sway with increase in angular disparity only for hand and foot stimuli but not for whole-body stimuli with an egocentric transformation strategy.

5 Limitation

One limitation of these studies is that they only involved young and healthy sport science students. It is possible that these participants had higher motor expertise than the general population, which may have made the challenges of dynamic stability too easy for them. It is worth noting that there is a known relationship between mental rotation ability and motor expertise (Steggemann et al., 2011; Voyer & Jansen, 2017), which could have influenced the results. Future research could investigate whether similar outcomes are observed when older adults or children perform the tasks. As it was observed in previous studies (e.g., Cerella et al., 1981; Lord & Marsh, 1975) the mental-rotation performance tends to decline with age and it would be of interest, if this is also the case when participants perform a mental body-rotation task under conditions with different perturbations. Moreover, an analysis of gender differences could prove enlightening. In particular, research (for a meta-analysis see Voyer, 2011) has demonstrated that gender differences are especially evident in paper-pencil tests with time constraints, with men outperforming women. It is therefore essential to examine, whether these findings extend to the stimuli and test conditions employed in the mentioned studies. Further research is required to better understand the influence of embodiment in mental rotation tasks on postural stability. It may be necessary to include more challenging motor tasks, such as standing on one leg or standing on one leg on an unstable surface, to explore any potential relationship. A further methodological limitation is imposed by the stimulus material. In the experiments presented, only female stimuli were employed. Even when these were presented from behind, a female person was clearly recognizable. In future studies, it is advisable to take this into account and to verify the stimulus material regarding gender.

6 Conclusion

In conclusion, the aim of the present studies was the investigation of the relationship between dynamic stability and mental body rotation. The results showed that there was no influence of different balance demands on two different MBRTs when they were performed under conditions of active balance control (Study 1, 2, and 3, Experiment 1) and under conditions of re-active balance control (Study 3, Experiment 2). No significant differences could be observed between performing the MBRT in a parallel standing position on even ground (low demands), standing on a balance beam or a balance board (high demands), or standing on a vibrating platform with different levels of vibration intensity. Taken together, the results of Studies 1-3 suggest that postural control processes do not interfere with perceptual-cognitive processes, such as the performance of mental body rotation tasks. Therefore, it appears that embodied processes may not have influenced the performance of the participants. This conclusion remains valid for active balance control in sitting versus standing (Study 1), standing versus balancing on a balancing beam (Study 2), and standing versus balancing on a balance board (Study 3, Experiment 1). Additionally, it holds true for re-active balance control when comparing different intensities evoked by a vibration plate (Study 3, Experiment 2). Furthermore, performing a mental rotation task while standing in a parallel position result in similar postural sway parameters as performing a no-mental-rotation task. However, there is a difference between the two types of mental rotation tasks: An egocentric transformation task leads to greater postural stability compared to an object-based transformation task that uses whole human bodies as stimuli. Further studies should be conducted to determine whether this pattern of results is also applicable to participants of other age groups, including older adults, children, and adolescents.

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Part II - Cumulus

Chapter I

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

Citation of publication

Budde, K., Barela, J. A., Figueiredo, G. A., & Weigelt. M. (2020). Mental body rotation with egocentric and object-based transformations in different postures: sitting vs. standing. *Brazilian Journal of Motor Behavior, 14*(2), 73-84. https://doi.org/10.20338/bjmb.v14i2.165

Abstract

BACKGROUND: A detail of previous studies on mental rotation, which has not received any attention so far, relates to the testing situation of the participants. In nearly every study, participants were tested in a sitting posture (and not standing). However, when considering embodied cognition approaches on mental processes, participants may not be able to fully exploit these processes when performing mental rotation tasks in a sitting posture.

AIM: Therefore, the aim of the present study is to examine the potential influence of two different postures (sitting vs. standing), when solving mental body rotation tasks.

METHOD: Sixteen participants (6 females) were tested in two mental body-rotation tasks (MBRT), requiring either an object-based spatial transformation (based on a same-different judgment) or an egocentric transformation (based on a left-right judgment) in a sitting and in a standing posture. Reaction times and response errors were analyzed in two three-way ANOVAs, with the factors orientation, task, and posture.

RESULTS: Results revealed an effect of orientation and task, indicating that participants performed better for egocentric than for object-based transformations. However, there was no effect of posture.

CONCLUSION: The different dynamics of postural control during sitting and standing do not induce different embodiment effects on mental rotation.

Introduction

The mental rotation task (MRT) by Shepard and Metzler (1971) is a widely used paradigm to test people's visual spatial abilities in cognitive psychology. According to Steggemann-Weinrich and Weigelt (2019), mental rotation skills signify people's "ability to spatially transform two-dimensional or three-dimensional objects or bodies from one orientation in mental space to another" (p. 173). In the standard MRT, two pictures of three-dimensional objects are shown side-by-side, whereupon one picture serves as a reference image and is therefore presented in an upright position and the other picture is displayed at various orientations. Participants' task is to decide if the two pictures depict the same or different objects (i.e., same-different judgment), regardless of the differences in orientation (e.g., Shepard & Metzler, 1971). Besides this classical MRT, previous studies have used a variety of different stimuli to examine the mental rotation skills using the psychometric testing approach. These included two-dimensional shapes (e.g., Cooper, 1975), letters (e.g., Voyer et al., 2017), images of human body parts (e.g., Bläsing et al., 2013), or whole human bodies (e.g., Amorim et al., 2006). The present study investigates the mental rotation of[1] human bodies in an extension of the standard MRT by Shepard and Metzler (1971), which is called the mental body-rotation task (MBRT) (Jola & Mast, 2005).

In general, three types of transformations can be distinguished based on an environmental reference frame, an egocentric reference frame, and an object-based reference frame (Zacks & Michelon, 2005; Zacks et al., 2002). The environmental reference frame is defined relative to a fixed point of the environment, locating things relative to axes with respect to a fixed space. In contrast, the egocentric reference frame is defined relative to the self. Humans use this egocentric reference frame with the axes up-down, front-back, and left-right. The object-based reference frame is the third type of spatial reference frame, which is defined relative to external objects. The object-based reference frame can be used either for characterizing the relationship between the parts of an object independent of the object´s location in the environment or to locate an object relative to another object (Zacks & Michelon, 2005).

A detail of most of all previous studies on mental rotation, which has not received any attention so far, relates to the testing situation of the participants. That is, participants were

[1] Besides the computer-based approach (psychometric testing approach), there is also the chronometric approach to test for mental rotation abilities. Methodologically, it is based on a paper-and-pencil version of the mental rotation test (MRT), developed by Vandenberg & Kuse (1987), and has been used in many different versions (for a meta-analysis see Voyer, 2011). The chronometric approach, however, is not within the focus of the present study and will therefore not be further addressed.

always tested in a sitting posture (and not standing; but see Kaltner et al., 2017). This certainly reflects the “natural” test scenario of laboratory research. However, when considering embodied cognition approaches on mental processes (e.g., Barsalou, 1999; Wexler et al., 1998; Wilson, 2002), it could be argued that participants may not be able to fully exploit these processes when performing mental tasks in a sitting posture. The theoretical framework of embodied cognition states a strong link between motor and mental processes, meaning that cognitive processes are deeply rooted in the body´s interaction with the environment (e.g., Wilson, 2002). There are two kinds of embodiment, which can explain the performance of spatial transformation: The first is spatial embodiment and assumes a bodily projection of the own body axe onto the embodied object, such as for the stimulus material in a MBRT. The second is motoric embodiment and suggests that the processes of imagining, observing, and executing actions all share the same motor representations (e.g., Barsalou, 1999). In addition, Schütz-Bosbach and Prinz (2007) distinguish between offline and online effects in terms of embodied cognition. Online effects refer to the phenomenon, that ongoing actions influence the perception of similar or different actions. Offline effects are based on past movement experiences, which are stored in motor representations. These motor representations influence perception and decision making, even when a person is not moving (Schütz-Bosbach & Prinz, 2007).

Interestingly object-based and egocentric transformations differ in the amount of embodiment. While object-based transformations rely on object-centered representations, egocentric (perspective) transformations rely on simulated movements of the own body, where proprioceptive information is more relevant (e.g., Zacks & Michelon, 2005). Therefore, for object-based spatial transformations (based on same-different judgments), it may not make a difference whether participants are sitting or standing. For egocentric transformations (based on left-right judgments), however, the posture in which participants perform may well influence their performance, especially, when they must rotate human figures, because under these conditions, participants most likely solve the task by drawing on own embodied representations of left and right (e.g., Jola & Mast, 2005; Zacks et al., 2002).

There are experimental observations from two different research areas, which suggest that the posture in which participants solve other perceptual-cognitive tasks, affects performance. The first observation comes from research on perceptual learning and was made rather by coincidence. Here, Faubert and Sidebottom (2012) examined high-level athletes from ice hockey, rugby, and soccer in a multiple-object tracking-task over an extended period of training (over 30 training sessions). These athletes were all sitting during the acquisition of the task (i.e.

tracking multiple objects) and did not differ in the level of performance at the end of the study (as signified by similar learning curves). However, when they collected additional data from another ice hockey team, which was standing during the complete training period, they found that these athletes performed worse (as signified by flatter learning curves) than the athletes, who were sitting before. Faubert and Sidebottom (2012) attributed this surprising result to differences in motor load between the two posture conditions (sitting vs. standing) and stated that this “clearly demonstrates the link between balance control mechanisms and perceptual-cognitive demands” (p. 95).

The second observation comes from research by Bray and colleagues (2004), who tested the link between different body positions and performance in a (subjective) visual judgment task. In their study, participants were asked to align a tilted rod to the earth’s vertical. To give misleading cues to verticality, a rectangular frame surrounded the rod. In each trial, the experimenter tilted the frame to left or right and/or set the rod to left or right at a random angle of 25°-35° from the earth’s vertical. Thereupon, participants had to adjust the rod to the earth’s vertical. Importantly, they were tested under three different posture conditions: sitting on a chair, standing “at ease”, and standing on a beam “balancing”. As the results revealed, participants set the rod more accurately to the vertical line while they were balancing on the beam, as compared to the standing “at ease” and the sitting condition. The authors stated that this “suggests that information from the dynamics of balance improves the perception of orientation” (Bray et al., 2004, p. 609).

The aim of the present study was to investigate the influence of embodied processes on the mental rotation of human bodies. With regards to previous studies, the following predictions were made: First, it is expected that participants perform generally better in the MBRT for egocentric transformations (as compared to the performance for object-based transformations) (e.g., Jola & Mast, 2005). This should be reflected in the faster mental rotation times (as signified by a shallow RT-slope over different rotation angles) of human bodies, when the task requires a left-right judgment, and slower mental rotation times (as signified by a steeper RT-slope over different rotation angles), when the task requires a same-different judgment. Second, mental rotation performance should be influenced by the body posture in which participants solve the task (e.g., Bray et al., 2004; Faubert & Sidebottom, 2012). The different results of the two previous studies can be explained by task differences implying different task dynamics, as the dynamics of a tracking task (Faubert & Sidebottom, 2012) is quite different than the perception of vertical lines/rods (Bray et al., 2004). Arguably, the results of Bray and colleagues

(2004) are somewhat more relevant to the present study, because of the nature of the MBRT (i.e., visual-spatial alignment of human bodies).

Methods

Sample

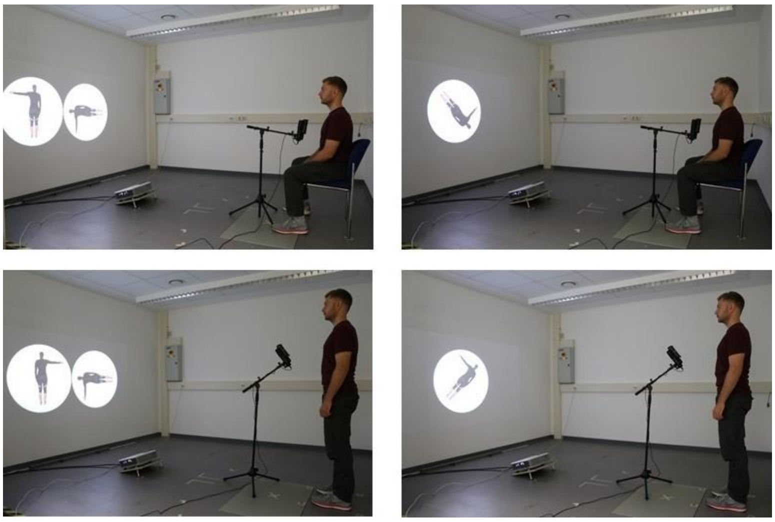
Sixteen volunteers (6 females; mean age = 23.5 years, age range 18 - 36 years) with normal or corrected-to-normal vision participated in this experiment. They characterized themselves as neurologically healthy. All participants were students at the University of Paderborn in Germany and German was their native language. They were not paid for their participation but received course credit. Before being tested, everyone gave his or her written informed consent. None of the participants took part in any mental rotation experiment prior to this study. The study was approved by the local ethics committee of the university and was carried out in accordance with the Helsinki Declaration of 1975.

Apparatus

The experimental set-up can be seen in Figure 1. 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 or sitting on a chair, 3 meters away from the wall. The stimuli appeared in a size of 100 cm in diameter on a black screen. Verbal responses were given with a microphone (Rhode) linked via an usb-port with the computer. The threshold value for the microphone to be activated was adjusted to 0.1 % of the maximum sound recording level.

Figure 1

Experimental set-up under the different tasks and conditions.



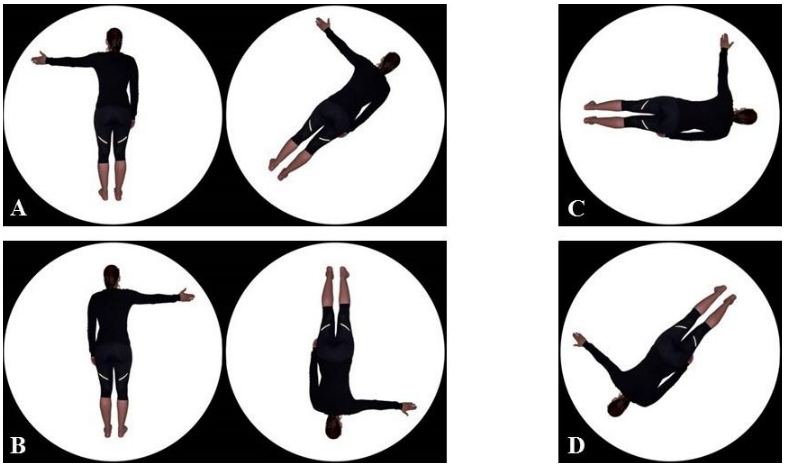
Note: Left panel, the task scenario for the same-different judgement is displayed for the sitting posture (picture on the top) and the standing posture (picture on the bottom). Right panel, the task scenario for the left-right judgement is depicted for the sitting posture (picture on the top) and the standing posture (picture on the bottom).

Stimulus Material

Stimuli were taken from Steggemann et al. (2011). There were two different mental rotation tasks: One 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 arm or the right arm extended, were presented simultaneously on the screen. 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°), resulting 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 the 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.

Figure 2

Examples of stimuli used in the experiment.



Note: (A) same-different judgment with 45° angular disparity, same pictures; (B) same-different judgment with 180° angular disparity, different pictures; (C) left-right judgment with 90° angular disparity, left arm outstretched; (D) left-right judgment with 225° angular disparity, right arm outstretched.

Procedure and Task

The test session lasted about 45 minutes and took place in the laboratory. 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 presented stimulus on the right side was identical to the comparison stimulus on the left side. In the object-based transformation, participants 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, only one picture of a woman in back-view perspective was presented. Participants were asked to determine as quickly and as accurate as possible whether the person raised her left arm 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. Participants were tested in four blocks: (A1) object-based transformation task and standing posture, (A2) object-based transformation task and sitting posture, (B1) egocentric transformation task and standing posture and (B2) egocentric transformation task and sitting posture. Half of the participants started with two blocks in the object-based transformation task (A1 and A2), while the other half started with two blocks in the egocentric transformation task (B1 and B2), before continuing in the other condition, respectively. Moreover, the order of the posture sitting vs. standing was balanced for the two tasks. The following four different orders of blocks were tested: (1) A1, A2, B1, B2; (2) A2, A1, B2, B1; (3) B1, B2, A1, A2; and (4) B2, B1, A2, A1.

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 German word “Fehler” appeared on the screen. Feedback was given for 1000 ms.

To familiarize themselves with the stimuli and the tasks, participants performed two practice sessions: one with 32 test trials before the first block of the two blocks of the object-based transformation task and one with 16 test trials before the first of the two blocks of egocentric transformation task. The order of the trials within the practice session was randomized.

The entire experiment consisted of four test blocks (A1, A2, B1, B2) of 160 experimental trials in the two object-based transformation tasks (A1, A2) and 80 experimental trials in the two egocentric transformation tasks (B1, B2), resulting in 480 trials in total. 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 five times in each test block. The 80 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 five repetitions of each combination. In the object-based transformation task, half of the trials showed the same and the other half showed different images. In the egocentric transformation task, half of the trials showed the person raising the left arm and half of the trials displayed the person raising the right arm. The order of the presentation of the stimuli was randomized. Between the blocks, participants could decide how long they wanted to have a break.

Data analysis

Data (response time and response error) were recorded by using the software “Presentation” and analyzed with two three-way ANOVAs, including the factors angular disparity (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°), MR task (object-based vs. egocentric), and posture (standing vs. sitting), as independent variables, and response time (RT) and response error (RE), as dependent variables. RTs faster than 100 ms (0 %) and slower than 1500 ms (2,34 %) were defined as outliers and excluded from statistical analysis, as well as data from incorrect trials (1,76 %). As incorrect trials, we considered trials in which participants’ answer was wrong. Correct (RT) and incorrect (RE) trials were analyzed separately. 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.

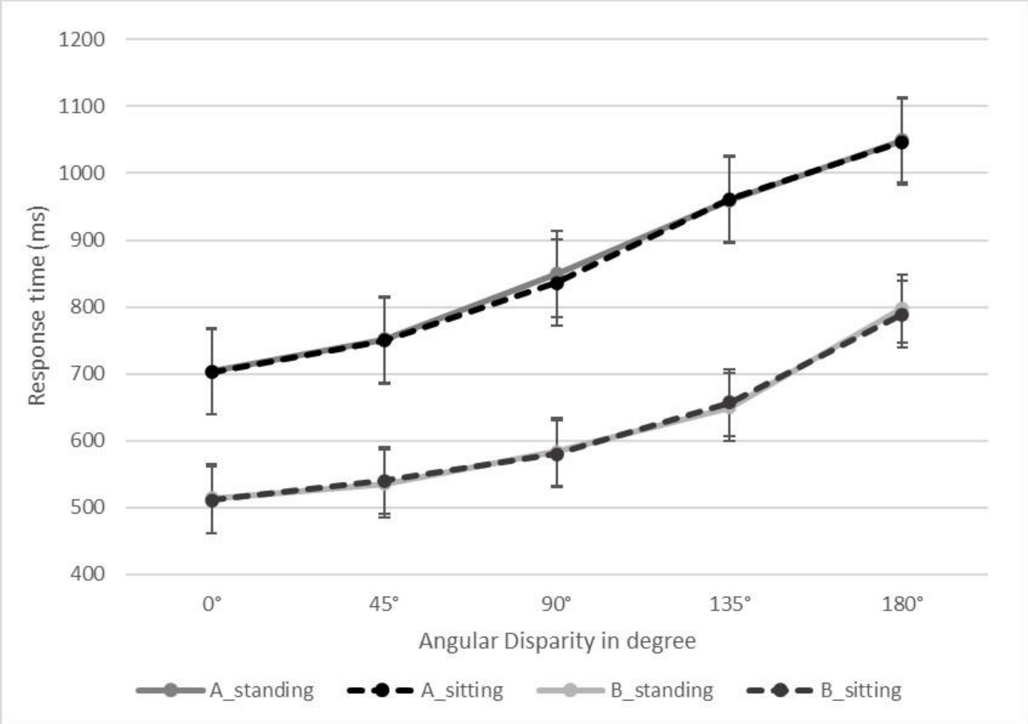
Results

Response Time

The RT pattern for the two postures in the object-based spatial transformation (A) and in the egocentric perspective transformation (B) can be seen from Figure 3. The ANOVA displayed a main effect for MR task, $F(1, 15) = 154.664$, $p < .001$, $\eta^2p = .912$. Accordingly, participants were significantly faster in the egocentric transformation (M = 616 ms, SD = 69 ms) than in the object-based transformation (M = 861 ms, SD = 101 ms). There was also a main effect of angular disparity, $F(1.363, 20.440) = 218.357$, $p < .001$, $\eta^2p = .936$, 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 interaction between condition and angular disparity reached significance ($F(1.650, 24.755) = 11.455$, $p = .001$, $\eta^2p = .433$), whereupon the increase of rotation angle had a greater impact on object-based transformation. Post-hoc t-test showed significant mean differences for all increases in angular disparity (all $p < .005$), except the last one between 135° and 180° ($p = .052$). There was no main effect for posture and no significant two-way interaction, neither between condition and posture, nor between posture and angular disparity. Furthermore, the three-way interaction between angular disparity, stimulus condition and posture also failed to reach significance.

Figure 3

Response Time (RT).



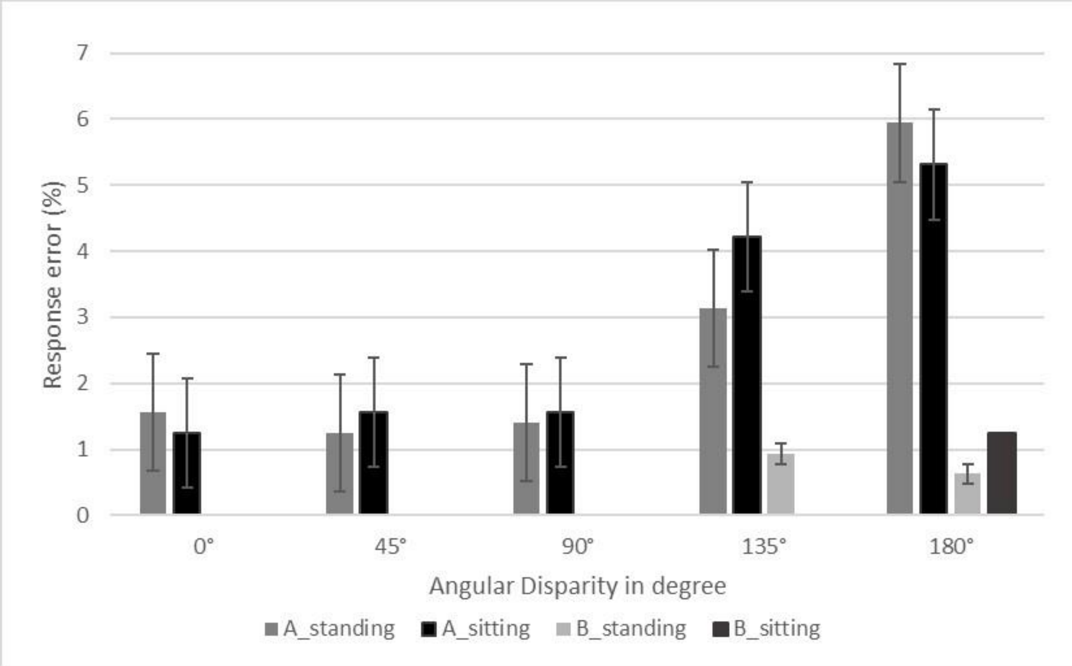
Note: Mean response times (RT) in milliseconds (±SE) for the object-based transformation (A) and the egocentric transformation (B).

Response Error

Figure 4 provides the RE pattern for both postures in the object-based spatial transformation (A) and the egocentric perspective transformation (B). The ANOVA revealed a main effect of MR task ($F(1, 15) = 16.617$, $p = .001$, $\eta^2p = .526$), showing that participants committed significantly more mistakes in the object-based transformation (2.7%) than in the egocentric transformation (0.3%). Also, a main effect for angular disparity ($F(1.847, 27.710) = 5.917$, $p = .008$, $\eta^2p = .283$) was found. Post-hoc t-test revealed that RE differed significantly only between rotation angles of 90° and 135° ($p = .036$). Moreover, there was a significant interaction between condition and angular disparity ($F(1.903, 28.549) = 4.533$, $p = .021$, $\eta^2p = .232$). Post-hoc t-test showed only a significant mean difference between 90° and 135° ($p = .044$). There was no main effect for posture and no significant two-way interaction between condition and posture, as well as between posture and angular disparity. Furthermore, there was no three-way interaction between condition, posture, and angular disparity.

Figure 4

Response Error (RE).



Note: Mean response error (RE) as percentages (SE) for the object-based transformation (A) and the egocentric transformation (B).

Discussion

The aim of the present study was to investigate the influence of embodied processes on the mental rotation of human bodies. Therefore, for the first time, participants performed two MBRT in a sitting and in a standing position. In one MBRT, two pictures of a female person in back view perspective were presented and participants were asked for a same-different judgment, whereas in the other MBRT, only one picture of a female person in back view rising her left or right arm was displayed and the task required a left-right judgment. According to Zacks and colleagues (2002, 2005) and Jola and Mast (2005), the first MBRT induced an object-based transformation and the second MBRT induced an egocentric transformation in the participants.

In general, the results confirmed the predictions derived from previous studies on mental rotation of human bodies (e.g., Jola & Mast, 2005; Kaltner & Jansen, 2018; Kaltner et al., 2014; Pietsch & Jansen, 2018). That is, RTs and REs increase for visual-spatial transformations of human bodies, the more the stimuli have to be mentally rotated. In addition, participants performed better for egocentric transformations (i.e., requiring a left- right judgment) than for object-based transformations (i.e., requiring a same-different judgment), as reflected in faster response times and fewer errors. Thus, using a similar argumentation as other authors of previous studies (e.g., Jola & Mast, 2005; Parsons, 1987), aligning oneself into the person displayed is faster than to spatially align and compare two objects.

Concerning the specific testing situation, it was expected that embodied processes would influence the mental rotation of human bodies, depending on the body posture in which participants solved the task (sitting vs. standing) (Bray et al., 2004; Faubert & Sidebottom, 2012). One previous study on the perception of visual orientation demonstrated better performance when the balance of participants was challenged (Bray et al., 2004), whereas the opposite was observed during a study on perceptual training (Faubert & Sidebottom, 2012). In the present experiment, however, the two different postures examined did not lead to any effects on participants' mental rotation performance. From an embodiment perspective (e.g., Barsalou, 1999; Wexler et al., 1998; Wilson, 2002), the latter result is surprising, because it can be assumed, that the two different body postures (sitting vs. standing) challenged the dynamics of balance control to different degrees. However, the challenge for the dynamics of balance control may not have been big enough, given the task dynamics in the present experiment. Besides sitting and standing at ease, Bray et al. (2004) had participants also perform while standing on a balance beam, which poses a greater challenge to the dynamics of balance control. This notion is supported by the observation, that the coupling between visual information and body sway is affected in (young and older) adults, when the basis of support is being manipulated (e.g., Prioli et al., 2006). Thus, embodied processes may not have had a greater effect on participants' performance, because postural control processes (i.e., to keep static balance) did not interfere with perceptual-cognitive processes (i.e., to perform mental body rotations). Future studies should therefore examine participants' mental rotation performance under conditions in which their balance is challenged to a greater degree (e.g., on a balance beam).

It could be, however, that embodied processes influenced the mental rotation of human bodies but were not detected in the present experiment. Arguably, the behavioral measures assessed (RT and RE) were not sensitive enough to show potential differences between the sitting and standing posture, although these measures are sufficient to demonstrate differences between egocentric transformations and object-based transformations (e.g., Kaltner & Jansen, 2018; Kaltner et al., 2014). A more sensitive measure may be to examine the dynamics of balance control as postural sway on a force plate. In fact, a previous study by Stins and colleagues (2017) has demonstrated, that the semantic processing of sentences involving different daily activities of high, low or no physical effort effected participants' body sway in a selective way. In a future study, participants should be placed on a force plate when solving mental rotation tasks.

Concerning the embodiment approach (e.g., Barsalou, 1999; Wexler et al., 1998; Wilson, 2002) and the online and offline effects mentioned by Schütz-Bosbach and Prinz (2007), processes of action and perception influence each other, because of similarity and contrast. Embodiment can help to encode and spatially represent rotated stimuli, as spatial embodiment moderates the mapping of one´s own body into the presented stimulus, based on the knowledge of body structure, while motoric embodiment moderates the postural spatial configuration during the mental rotation process. Therefore, mental rotation processes and embodiment can hardly be separated (e.g., Amorim et al., 2006). At the same time, there also seem to be limits to the embodiment argument, as in the present study, participants were similar able to map their own body representation to the stimulus figure while sitting or standing, suggesting that not all postural changes influence the performance in the MBRT.

Conclusion

For the first time, participants performed a MBRT in a sitting and standing position. It was of interest, if the different demands on balance control exhibited in these two postures would affect participants mental rotation performance. The present results did not show any differences between the two positions (sitting vs. standing, respectively), although previous studies have reported an influence of body posture on the perception of visual orientation (Bray et al., 2004) and on perceptual training (Faubert & Sidebottom, 2012). Future studies should consider to test participants in more challenging body postures (for example, placing participants on a balance beam) and to use more sensitive measures (for example, a force plate to assess body sway), in order to further examine mental rotation performance from an embodiment perspective (e.g., Barsalou, 1999; Wexler et al., 1998; Wilson, 2002).

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Chapter II

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

Citation of publication

Budde, K., Jöllenbeck, T., Barela, J. A., Figueiredo, G. A., & Weigelt. M. (2021). Mental body rotation with egocentric and object-based transformations in different postures: standing vs. balancing. *Brazilian Journal of Motor Behavior, 15*(3), 180-194.
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Abstract

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.

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" (Steggemann-Weinrich & Weigelt, 2019, p.173). In the classic chronometric mental rotation task (MRT), Shepard and Metzler (1971) 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 (e.g., Cooper, 1975), letters (e.g., Kaltner & Jansen, 2016; Voyer et al., 2017), images of human body parts (e.g., Bläsing et al., 2013), or whole human bodies (e.g., Amorim et al., 2006; Kaltner & Jansen, 2016, 2018; Kaltner et al., 2014; Pietsch & Jansen, 2018). The present study investigates the visual-spatial transformation of human bodies, which is an extension of the standard MRT by Shepard and Metzler (1971) and involves the mental rotation of whole-body figures. It has been therefore termed mental body-rotation task (MBRT) (Jola & Mast, 2005). For the mental rotation of human bodies, there are two types of transformations, which represent different cognitive strategies (e.g., Zacks et al., 2002). 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 (e.g., Kaltner et al., 2014; Pietsch & Jansen, 2018). 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 (2015), 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 (e.g., Zacks & Michelon, 2005). 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 (e.g., Zacks et al., 2002).

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 (2004) 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 (e.g., Kaltner et al., 2014; Pietsch & Jansen, 2018; Voyer et al., 2017) 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 (e.g., Barsalou, 1999; Wilson, 2002). Based on this framework, Budde et al. (2020) 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 (e.g., Jola & Mast, 2005; Kaltner & Jansen, 2018; Kaltner et al., 2014; Pietsch & Jansen, 2018), 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 (2014) 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 (Budde et al., 2020). In line with this second argument, Dault and colleagues (2001) 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 (2021) 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 (2020) and taking the results of the previous studies (e.g., Dault et al., 2001; Hofmann & Jansen, 2021; Kawasaki et al., 2014) and the embodied cognition framework (e.g., Barsalou, 1999; Wilson, 2002) 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 (Hofmann & Jansen, 2021) as stimuli and one with stickman (Dault et al., 2001) 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 (e.g., Budde et al., 2020; Jola & Mast, 2005; Kaltner et al., 2014; Pietsch & Jansen, 2018; Steggemann et al., 2011), 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 (e.g., Bray et al., 2004; Kawasaki et al., 2014) 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 (e.g., Dault et al., 2001; Hofmann & Jansen, 2021).

Methods

Sample

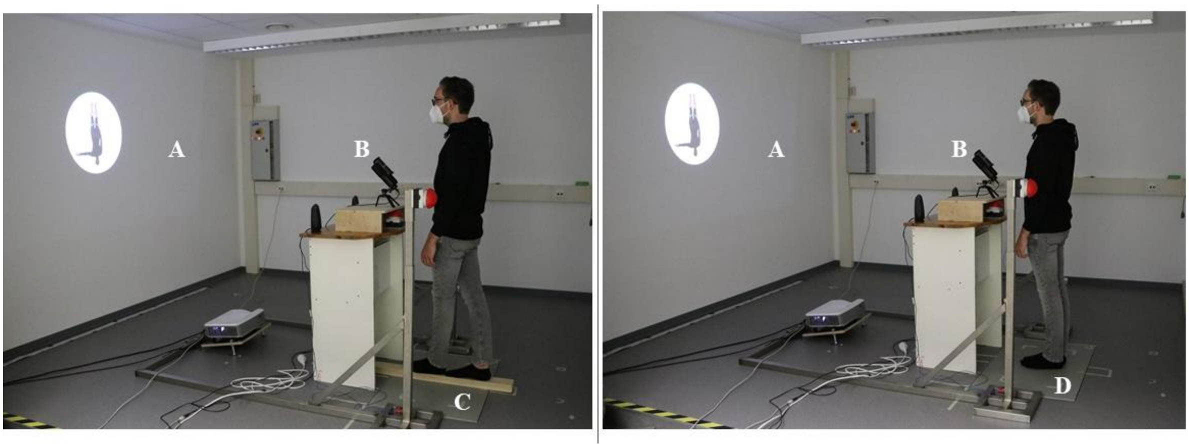
The study was carried out in accordance with the Helsinki Declaration of 1957 and was approved by the local ethics committee of the university. A total of 30 sport science students (18 females, mean age = 21.2 years, age range 18-25 years, 4 left-handers; 12 males, mean age = 21.3 years, age range 19-28 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 diameter22 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.



Note: 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

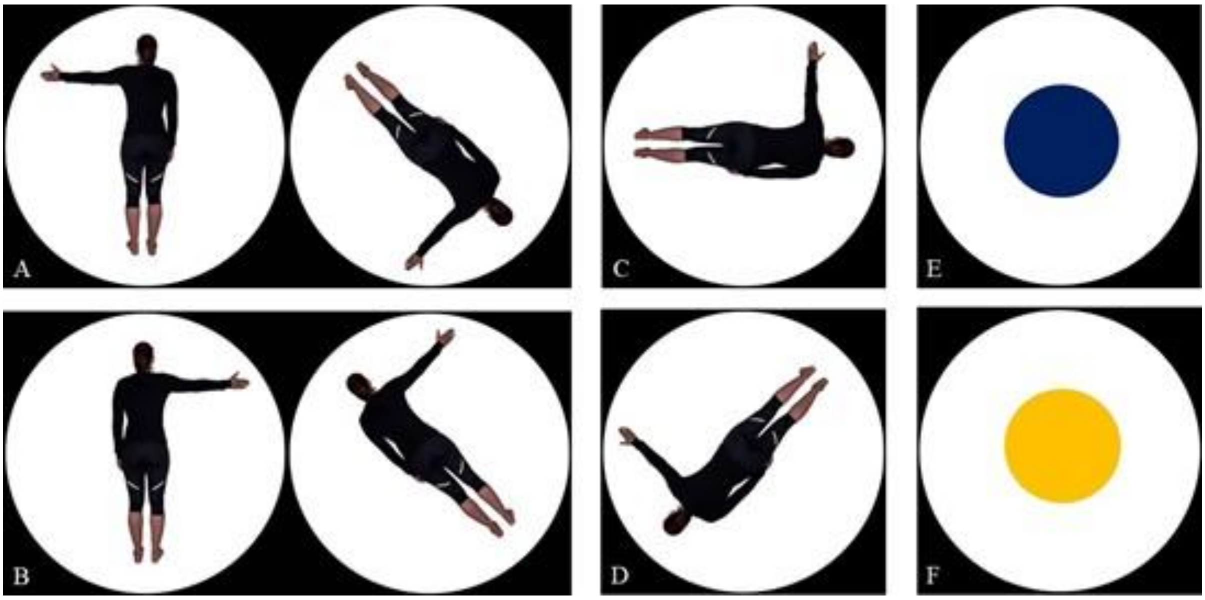
The stimuli for the two different MBRTs were taken from Steggemann and colleagues (2011). One of the tasks required an object-based spatial transformation and the other an egocentric perspective transformation (see Figure 2). In the object-based transformation, two images of a female person in back view 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.



Note: (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)

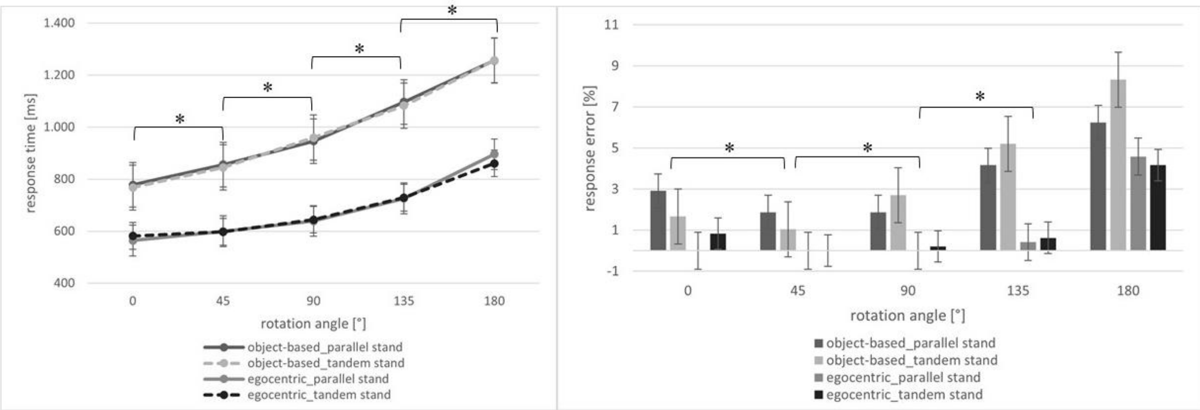
Figure 3 provides the RT pattern for both postures in the object-based transformation and the egocentric perspective transformation. The ANOVA revealed a main effect of condition, $F(1, 29) = 140.43$, $p < .001$, $\eta 2p = .83$, showing that participants were significantly faster in the egocentric transformation task ($M = 683$ ms) than in the object-based transformation task ($M = 984$ ms). The ANOVA also revealed a main effect of rotation angle $F(1.5, 44.5) = 174.39$, $p < .001$, $\eta 2p = .86$, 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 ($F(2, 58) = 18.71$, $p < .001$, $\eta 2p = .39$), 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 ($F(1, 29) = 41.03$, $p < .001$, $\eta 2p = .59$). 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 ($F(1.69, 48.88) = 14.13$, $p < .001$, $\eta 2p = .33$). 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).



Note: 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.

	Conditions										
Parameter	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)

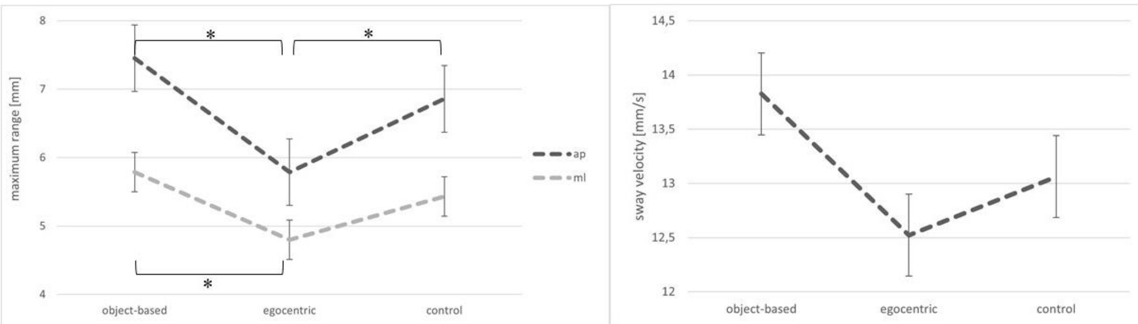
Note: Mean values (SD) for the three conditions and the different rotation angles. Range ap = maximum range of CoP in anterior-posterior direction, range ml = maximum range of CoP in medial-lateral direction, sv = sway velocity.

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 ($F (2, 58) = 4.30$, $p = .018$, $\eta 2p = .13$). 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 ($F (1.66, 48.12) = 4.91$, $p = .016$, $\eta 2p = .15$). 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 ($F (1.66, 48.12) = 4.91$, $p > .05$, $\eta 2p = .15$).

Figure 4

Comparison MBRT and control condition.



Note: 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.

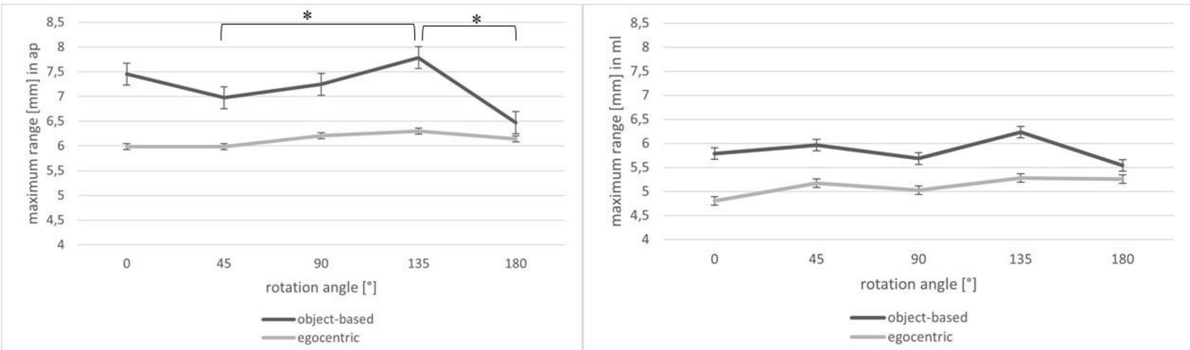
MBRT and rotation angles

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, η2p = .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, η2p = .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, η2p = .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, η2p = .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

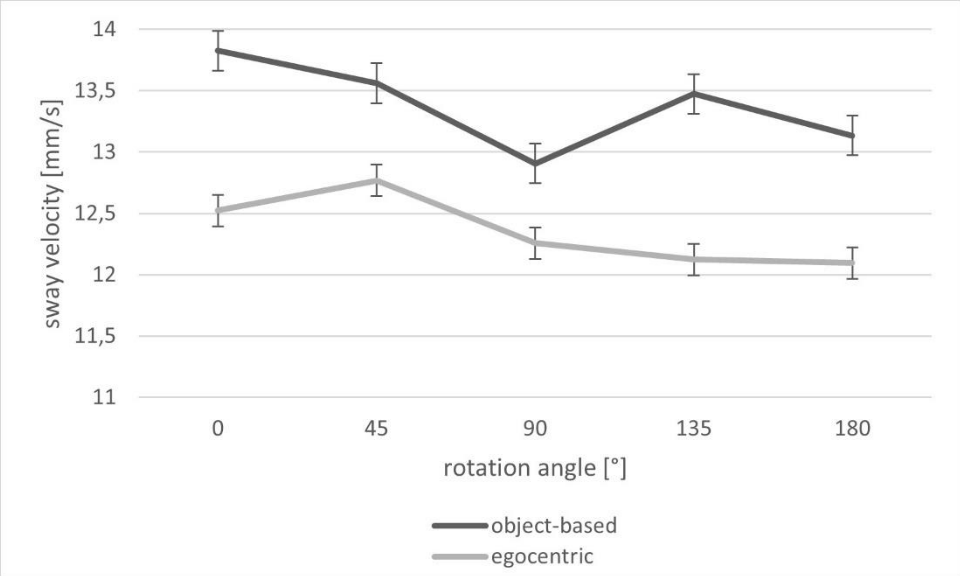
Maximum range of CoP.



Note: 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 angles.

Figure 6

Sway velocity of CoP.



Note: 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 (e.g., Budde et al., 2020; Jola & Mast, 2005; Kaltner & Jansen, 2018; Kaltner et al., 2014; Pietsch & Jansen, 2018; Steggemann et al., 2011). 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 (e.g., Jola & Mast, 2005; Parsons, 1987).

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 (e.g., Barsalou, 1999; Wilson, 2002; Wexler et al., 1998). 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 (Bray et al., 2004), 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 (Budde et al., 2020), 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 (e.g., Prioli et al., 2006). 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 (e.g., Dault et al., 2001; Hofmann & Jansen, 2021; Kawasaki et al., 2014). 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 (2021), 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 (2021) 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 (Hofmann & Jansen, 2021). This was also the case in the study by Dault and colleagues (2001), 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 (Dault et al., 2001; Hofmann & Jansen, 2021). 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 (2021), 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 (2015) and Zacks and Michelon (2005), 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 (Hofmann & Jansen, 2021; Kawasaki et al., 2014). 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 (Dault et al., 2001; Hofmann & Jansen, 2021) 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 (Dault et al., 2001; Hofmann & Jansen, 2021), 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.

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Chapter III

No effects of different perturbations on the performance in a mental body-rotation task (MBRT) with egocentric perspective transformations and object-based transformations

Citation of publication

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Abstract

The present study investigates participants' performance in two different mental body-rotation tasks (MBRTs) under conditions in which dynamic stability is challenged in two different balancing conditions: active balance control (Experiment 1), where participants actively maneuver, and re-active balance control (Experiment 2), where participants react to an external perturbation. The two MBRTs induced either an object-based spatial transformation (based on a same-different judgment) or an egocentric transformation (based on a left-right judgment). In Experiment 1, 48 participants were tested while standing on an even ground (low balancing requirements) or on a balance board (high balancing requirements). In Experiment 2, 32 participants performed while either standing still on a vibration plate or with the vibration plate moving in a low (20 Hz) or high (180 Hz) frequency. In both experiments, the results for response time and response error revealed effects of rotation angle and type of task. An effect of balancing condition was only observed for response error in Experiment 1. More precisely, response times and response errors increased for higher rotation angles. Also, performance was better for egocentric than for object-based spatial transformations. However, the different challenges to dynamic stability in Experiments 1 and 2 did not influence performance in the two MBRTs (except for response errors in Experiment 1) nor in a control condition (Experiment 1) without mental rotation.

Introduction

Balance is an essential capability to ensure an upright stance and it seems that standing upright is one of the easiest motor tasks to perform (at least for adults). However, external perturbations can challenge dynamic stability during daily life, for example, when performing a cognitive task (e.g., Andersson, Hagman, Talianzadeh, Svedberg, & Larsen, 2002; Mujdeci, Turkyilmaz, Yagcioglu, & Aksoy, 2016). Although controlling dynamic stability during upright stance seems to be easy, the typical test scenario of laboratory research in mental rotation examines participants' performance while they are sitting on a chair (e.g., Habacha, Lejeune-Poutrain, & Molinaro, 2017; Kaltner, Riecke, & Jansen, 2014; Pietsch & Jansen, 2018). Thus, until now, little is known about the relationship between postural control and the cognitive task of mental rotation.

The mental rotation task (MRT), which has become a widely used paradigm in cognitive psychology, was first introduced by Shepard and Metzler (1971) and examines peoples' "ability to spatially transform two-dimensional or three-dimensional objects or bodies from one orientation in mental space to another" (Steggemann-Weinrich & Weigelt, 2019, p. 173). In the standard MRT, participants are asked to view two images of three-dimensional objects shown side-by-side, which are displayed in the same or different orientations in space (Shepard & Metzler, 1971). Participants' task is to judge whether the two images presented display the same or different objects. The typical pattern of results shows that response times and judgment errors increase linearly with increasing angular disparity, signifying the cognitive effort required to transform the objects in mental space. Today, the findings for the standard MRT have been generalized to a variety of different stimuli, as for example, the mental rotation of two-dimensional objects (e.g., Cooper, 1975), alphanumeric characters (e.g., Cooper & Shepard, 1973), images of human body parts (e.g., Bläsing, Brugger, Weigelt, & Schack, 2013), or whole human bodies (e.g., Amorim, Isableu, & Jarraya, 2006; Kaltner & Jansen, 2016; Pietsch & Jansen, 2018). The present study focuses on the mental rotation of human bodies in a so-called mental body-rotation task (MBRT, Jola & Mast, 2005).

In spatial cognition, two types of mental transformation strategies can be distinguished, an object-based transformation strategy and an egocentric perspective transformation strategy (Zacks, Mires, Tversky, & Hazeltine, 2002), respectively. For object-based transformations, an object is mentally rotated relative to a reference frame in the environment, while the observer's position stays fixed. For egocentric perspective transformations, the observer's point of view relative to a reference frame is updated, while the position between an object and the environment remains fixed. How participants solve a mental rotation task with human bodies depends on the type of judgment that must be made. When two images are presented side-by-side, one object serves as a reference frame, while the other object is spatially transformed and compared to this reference frame. In this test scenario, participants are asked to perform a same-different judgment for these two images, which is based on an object-based transformation. In contrast, when a single image of a human body is presented and participants' task is to perform a left-right judgment (e.g., when the left or right arm is stretched out), it induces an egocentric perspective transformation. In this test scenario, the participant's reference frame is aligned with that of the human body displayed (Zacks et al., 2002).

Based on the theoretical framework of embodied cognition, object-based transformations and egocentric perspective trans- formations may benefit from the involvement of motor processes. This implies that mental rotation skills, which were originally thought to be based exclusively on "pure" cognitive processes (e.g., Wilson, 2002), seem to have a motor component. This means, that when performing a cognitive task, our brain is not the only source we make use off, but also our body and the corresponding motions are involved (Wilson, 2002). In the context of mental rotation skills, two kinds of embodiment can explain the performance of spatial transformation: The first one, spatial embodiment, supposes a bodily projection of one's own body axis onto the embodied object. The second is motoric embodiment and assumes that processes of imagining, observing, and executing actions all share the same motor representations (Barsalou, 1999). Furthermore, the two kinds of spatial transformation strategies (object-based vs. egocentric perspective transformation) differ in the amount of embodiment. While egocentric perspective transformations rely on simulated movements of the own body, where proprioceptive information is more relevant, object-based transformations rely on object-centered representations (Zacks & Michelon, 2005).

Motivated by the embodied cognition framework (e.g., Barsalou, 1999; Wilson, 2002), Budde and colleagues (Budde, Barela, Figueiredo, & Weigelt, 2020; Budde, Jöllenbeck, Barela, Figueiredo, & Weigelt, 2021) aimed to systematically examine the influence of different body postures and thus, the challenges to dynamic stability (i.e., different postural control demands) on participants´performance in two different mental body-rotation tasks (MBRTs). In the Budde et al. (2020) study, participants performed in the MBRTs with an egocentric perspective transformation and with an object-based transformation either in a sitting posture (i.e., sitting on a chair) or in a standing posture (i.e., parallel stance on an even ground). The aim was to examine the potential influence of these two postures on the performance in the two MBRTs. In line with previous studies (e.g., Jola & Mast, 2005; Kaltner et al., 2014; Pietsch & Jansen, 2018; Steggemann, Engbert, & Weigelt, 2011), participants performed better for egocentric perspective transformations than for object-based transformations, as reflected in faster response times and fewer response errors. Most interestingly, however, there was no effect of the body posture (i.e., sitting vs. standing) in which participants solved the task (Budde et al., 2020). This observation was at odds with another series of previous studies, showing improved performance in visual-spatial processing when dynamic stability was challenged (e.g., Bray et al., 2004; Prioli, Cardozo, de Freitas Júnior, & Barela, 2006). The authors reasoned that this either reflected that the challenges of dynamic stability to balance control were not high enough to influence participants' performance or that the measurements taken (response time and response error) were not sensitive enough to reveal any effects.

Taking these two reasons into consideration, balance control was challenged in the Budde et al. (2021) study to an even greater degree, as participants were tested in a parallel stand on even ground and in a tandem stand on a balancing beam. Participants had to solve the same two MBRTs as in Budde et al. (2020), with an additional control task without any mental rotation. Especially, the authors investigated if these different demands on dynamic stability are reflected in postural sway parameters (parallel stand condition; Budde et al., 2021). Like in Budde et al. (2020), the results revealed better performance for egocentric perspective transformations than object-based transformations and greater response times and higher error rate with increasing rotation angle. However, one result was of further interest. According to the authors, „the analyzed Center of Pressure (CoP) data revealed a reduction of body sway during the MBRT for egocentric perspective transformations" (Budde et al., 2021, p.180). On the one hand, this provided evidence for different amounts of stabilization between the two MBRTs. In line with the observations from another recent study (e.g., Hofmann & Jansen, 2021), performing in the MBRT with egocentric perspective transformations leads to more postural stability than performing in the MBRT with object-based transformations, as being reflected in a lower range of motion in the anterior-posterior direction and the medial-lateral direction, as well as in a lower sway velocity. On the other hand, according to the embodied cognition approach, one would have expected that solving the MBRT requiring an egocentric perspective transformation generates more body sway than performing in a MBRT requiring an object-based transformation. That is, because in the egocentric perspective transformation task, one should be entrained to perform the rotation himself/herself (e.g., Stins, Schneider, Koole, & Beek, 2015; Zacks & Michelon, 2005), which should have been reflected in greater instability.

The present study

The dynamics of standing balance can be controlled in two ways: first, in an active fashion when perturbations in the environment are predictable (active balance control), and second, in a re-active fashion when postural disturbances occur unpredictable (e.g., Balasubramaniam & Wing, 2002; Pollock, Durward, Rowe, & Paul, 2000). The present two experiments further examine the link between postural control and mental rotation by distinguishing between these two different kinds of balance control, active balance control (Experiment 1) and re-active balance control (Experiment 2), respectively. In Experiment 1, participants maneuver on a balance board, actively controlling their balance (active balance-control condition), whereas in Experiment 2, participants react to external perturbations on a vibration plate with different vibration intensities (re-active balance-control condition). The focus of Experiment 1 is to further challenge dynamic stability to an even greater degree than has been done in previous studies (e.g., Budde et al., 2020, 2021), while participants actively control for their balance during two different MBRTs (i.e., requiring object-based vs. egocentric perspective transformations). The aim of Experiment 2 is to investigate another challenge to dynamic stability: The in- fluences of re-active balance control on the performance in a MBRT with egocentric perspective transformation. To this end, participants react to an external perturbation, which is evoked by a vibration plate. While participants are standing on the vibration plate, it is being moved with different intensities (low vs. high) in a horizontal direction. Since Experiment 2 focuses on a MBRT with egocentric perspective transformation, there is no MBRT with object-based transformation and no cognitive control condition.

Experiment 1: MBRT when standing on an even ground vs. on a balance board

Experiment 1 investigates participants' mental rotation performance under conditions of active balance control with different balancing requirements (low requirements vs. high requirements) and its potential influence on object-based vs. egocentric perspective transformations. To this end, participants solved two MBRTs, as well as a cognitive task without mental rotation (i.e., a color-naming task), while either standing in a parallel stand on an even ground (low balancing requirements) or on a balance board (high balancing requirements). The first research question addresses participants' mental rotation performance in the two MBRTs. Based on previous studies (e.g., Budde et al., 2020, 2021; Jola & Mast, 2005; Kaltner et al., 2014; Pietsch & Jansen, 2018; Steggemann et al., 2011), it is expected that participants perform better in the MBRT (as signified by faster response times and fewer error rates), when the task induces an egocentric perspective transformation strategy, as compared to an object-based transformation strategy. The second research question focuses on the different balance requirements. Here, previous research has demonstrated that visual-spatial pro- cessing improves for perceptual-cognitive tasks when postural control is (more or less) challenged (e.g., Bray et al., 2004; Kawasaki, Yasuda, Fukuhara, & Higuchi, 2014).

In the study by Bray et al. (2004), for example, participants had to align a tilted rod to the earth's vertical, which was surrounded by a rectangular frame. During the trials, the rod was tilted to left or right at different angles. Participants were asked to adjust the rod to the earth's vertical and were tested under three different postures: sitting, standing “at ease”, and standing on a beam “balancing”. Participants set the rod more accurately to the vertical when balancing as compared to the other two postures (Bray et al., 2004). Kawasaki et al. (2014) tested the relationship between performing a MRT and postural stability during unipedal and bipedal stance. Body stimuli (foot and hand) and car stimuli were presented in four different rotation angles and participants had to judge whether it is the left or right foot/hand or which side of the car headlights was painted. To measure postural stability, participants were standing barefoot on their non-dominant leg (unipedal standing) or with their feet closed together (bipedal standing), respectively. Results revealed a significant correlation between the performance (faster reaction times) in the MRT with foot stimuli (not for hand or car stimuli) and postural sway values (i.e., total length of sway and mean velocity) only during unipedal standing (Kawasaki et al., 2014). The authors suggested, that “the MR relates to the postural stability only when maintaining postural stability is more challenging condition” (Kawasaki et al., 2014, p. 45). If this holds also true for the present MBRTs, then performance should be better when participants stand on top of a balance board (i.e., high balance requirements) as compared to when they are standing in a parallel stand on an even ground (i.e., low balance requirements). In this regard, the control task (i.e., color-naming task) will inform about whether potential differences are related to the MBRTs.

Method

Sample

A sample-size calculation using the program “MorePower” (Version 6.0.4) was performed to calculate the optimal sample size. To this end, the alpha-level was set to 0.05, the power to 0.8, and the effect size ($\eta 2p$) to 0.08. The calculation revealed a sample size of $n = 48$. Therefore, a total of 48 sport science students (26 females and 22 males, mean age = 22.4 years, age range 19–29 years, 3 left-handers) with normal or corrected-to-normal vision participated in Experiment 1. Before the experiment started, all participants signed an informed consent form and filled out a short questionnaire. They characterized themselves as neurologically healthy, they were all native German speakers, and none of them took part in a comparable mental rotation experiment during the last six months. The students received course credits, but there was no financial or other benefit for participation. The study was approved by the local ethics committee of the university and carried out in accordance with the Helsinki Declaration of 1957.

Apparatus

The experimental set-up can be seen in Fig. 1. A beamer (Optoma) projected 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 even ground with their feet placed in a narrow parallel stand (for low balancing requirements) or standing on a balance board (for high balancing requirements). The top of the balance board consisted of a circular disk (40 cm in diameter) and the bottom of a semi- circular sphere, which provided only a small base of support for balance control on the ground. To keep the spatial positions between these two conditions similar, there was a mark on the floor for the standing position and for the balance board, respectively. Like in the study of Kaltner, Jansen, and Riecke (2017), who also present whole human bodies in a MBRT, the stimuli appeared in a size of 100 cm in diameter on a black screen and participants were placed 300 cm in front of the projection wall. Verbal responses were given with a microphone (Rhode) linked via an usb-port with the computer.

Stimulus material

The stimuli for the two different MBRTs were taken from Steggemann et al. (2011) and can be seen in Fig. 2. One of the tasks required an egocentric perspective transformation and the other an object-based spatial transformation. For the egocentric perspective transformation, a single image of a female person in back view with either the left or the right arm outstretched, appeared on a black screen. Therefore, a left-right decision was required. The image was rotated randomly in the picture plane (clockwise 0◦, 45◦, 90◦, 135◦, 180◦, 225◦, 270◦, 315◦), resulting in 16 different stimuli.

For 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 and a same-different decision was required. In each pair, the left image was arranged in an upright position (0◦) and the right one was rotated randomly in the picture plane (clockwise 0◦, 45◦, 90◦, 135◦, 180◦, 225◦, 270◦, 315◦), yielding in 32 different stimuli.

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

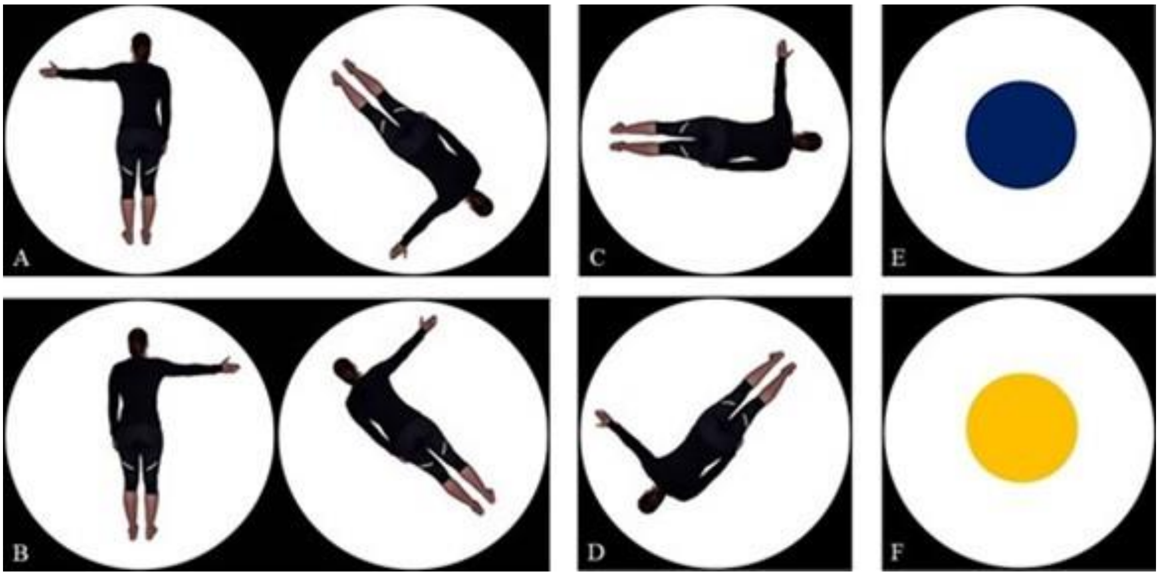
Figure 1

Experimental set-up of Experiment 1.

Note: Picture of the experimental set-up with the two balancing conditions (left: standing on a balance board, right: parallel stand on even ground). A: projector, B: wall on which the stimuli were projected, C: microphone, D: balance board.

Figure 2

Examples of stimuli used in Experiment 1 and 2.



Note: The figure demonstrates examples of stimuli used in the experiments. 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 took part in the laboratory and lasted about 40 min. Before starting the experiment, participants filled out a short questionnaire, gave informed consent, and read the standardized task introductions on their own. In the egocentric perspective transformation task, participants had to decide 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 object-based transformation task, participants were asked to determine 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). When the two stimuli were the same, they had to answer “gleich” (German word for “same”), and when the two stimuli were different, “ungleich” (German word for “different”). In the color-naming task (serving as a control condition), 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.

All three tasks were performed while standing in a parallel stand position on an even ground or while standing with both feet on a balance board. There was a mark on the ground to standardize the standing positions and 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 (even ground vs. balance board), was counterbalanced across participants. The entire experiment consisted of 384 trials, 64 experimental trials in each condition.

The 64 trials in the egocentric perspective transformation task were composed of two stimulus types (left or right arm raised) x eight rotation angles (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 object-based transformation task, each combination of the two images (original or mirrored), the stimulus pairs (same or different), and the eight angular disparities (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°) was presented two times in each test block. Half of the trials showed different, and the other half showed same images. In the color-naming task, each circle color was presented 32 times. In all three conditions the order of the stimuli was randomized. Before each new task, participants performed a practice session with 16 trials to familiarize themselves with the stimuli and the tasks. The order of the stimuli within the practice session was randomized for the egocentric-transformation task and the control condition, and pseudo-randomized for the object-based transformation task. Pseudorandomization in this case means, that a selection of 16 different stimuli were presented but not all 32 stimuli to ensure that the practice sessions have the same length. There was a short break between the blocks, with its length being self-selected by the participants.

The within-trial procedure was similar to our previous studies (Budde et al., 2020, 2021). In all conditions, each trial started with a black screen for 500 ms. After that, a white fixation cross appeared for another 500 ms, whereupon the stimuli were presented. The stimuli stayed on the screen until participants answered. In case of a wrong answer, participants received feedback and the word “Fehler” (German word for “error”) appeared on the screen for 1000 ms.

Data analysis

Data from the two MBRTs were analyzed within a three-way ANOVA, including the repeated factors task (egocentric trans- formation vs. object-based transformation), rotation angle (0°, 45°/315°, 90°/270°, 135°/225°, 180°), and balancing condition (low requirements: even ground vs. high requirements: balance board). Reaction times (RT) faster than 100 ms (0%) and slower than 2500 ms (1.12%) were defined as outliers and excluded form statistical analysis. Data from incorrect trials (2.51%) were discarded from data analysis for RTs and instead, separately analyzed in another ANOVA for response error (RE). Data from the practice sessions were not analyzed. The Greenhous-Geisser adjustment was used to correct for violations of sphericity and post-hoc t-test were Bonferroni-Holm adjusted. Data from the control condition (color-naming task) were analyzed in a two-way ANOVA including the factors task (egocentric transformation 0◦ vs. object-based transformation 0◦ vs. color naming) and balancing condition (low requirements: even ground vs. high requirements: balance board).

Results

Response time (RT)

Fig. 3 provides the RT pattern for both balancing conditions in the object-based transformation and the egocentric perspective transformation task. The ANOVA revealed a main effect of task, F (1, 47) = 160.73, p < .001, η^2_p = 0.77, showing that participants were significantly faster in the egocentric perspective transformation task (M = 668 ms) than in the object-based transformation task (M = 958 ms). The ANOVA also yielded a main effect of rotation angle F (1.67, 78.58) = 345.55, p < .001, η^2_p = 0.88, with the RT steadily increasing. Post-hoc *t*-tests indicated that RT differed significantly from each angular disparity to the next proximate one (all *p*'s = 0.004). The ANOVA also revealed an interaction of task and rotation angle (F (1.72, 80.82) = 29.12, p < .001, η^2_p = 0.38), whereupon the rotation angle had a greater impact on object-based transformation than on egocentric perspective transformation. Post-hoc *t*-test showed that response times between the two tasks differed significantly at all rotation angles (all p = .005). There was no main effect for balancing condition (F (1, 47) = 0.17, p = .679, η^2_p = 0.00) and no significant two-way interaction, neither between task and balancing condition (F (1, 47) = 0.17, p = .684, η^2_p = 0.00), nor between balancing condition and rotation angle (F (2.81, 132.20) = 0.86, p = .458, η^2_p = 0.02). Furthermore, the three-way interaction between task, rotation angle, and balancing condition also failed to reach significance (F (2.79, 130.88) = 0.86, p = .456, η^2_p = 0.02).

When comparing the control condition with the MBRTs, the ANOVA revealed a main effect of task (F (1.46, 68.42) = 0.45, p < .001, η^2_p = 0.84). Therefore, participants were faster in the control condition (M = 508 ms) than in the MBRTs, and faster in the egocentric transformation task (M = 565 ms) compared to the object-based transformation task (M = 751 ms).

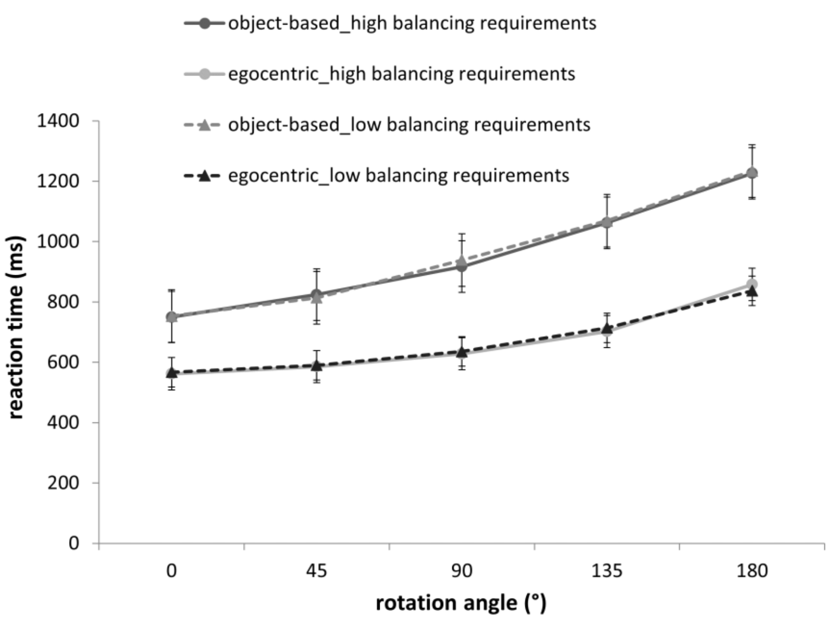
Post-hoc *t*-test showed that response times differed significantly between all tasks (all $p < .001$). There was no main effect for balancing condition (F (1, 47) = 0.04, $p = .843$, $\eta^2_p = 0.00$) and no interaction between the two factors (F (1.55, 72.75) = 0.60, $p = .509$, $\eta^2_p = 0.01$).

Response error (RE)

The RE pattern for the two balancing conditions in the object-based transformation and in the egocentric perspective transformation task can be seen from Fig. 4. The ANOVA revealed a main effect of task (F (1, 47) = 45.22, $p < .001$, $\eta^2_p = 0.49$). Accordingly, participants committed significantly more errors in the object-based transformation task (4.2%) than in the egocentric transformation task (1.3%). The ANOVA also revealed a main effect for rotation angle (F (1.94, 90.93) = 24.85, $p < .001$, $\eta^2_p = 0.35$). Post-hoc *t*-tests showed that RE differed significant between rotation angles 90◦ and 135◦ ($p = .004$), and between 135° and 180° ($p = .004$). Furthermore, there was also a main effect for balancing condition (F (1, 47) = 6.74, $p = .013$, $\eta^2_p = 0.13$), indicating that participants committed more mistakes when there were only low balancing requirements (standing on even ground = 3.1% errors), as compared to when there were high balancing requirements (standing on the balance board = 2.4% errors). Furthermore, the ANOVA revealed a significant two-way interaction only between the factors task and rotation angle (F (2.05, 96.35) = 5.02, $p = .008$, $\eta^2_p = 0.10$). Post-hoc *t*-tests showed that response errors between the two tasks differed significantly at all rotation angles (all $p < .05$). There was no other significant two-way interaction (task * balancing condition: F (1, 47) = 2.72, $p = .106$, $\eta^2_p = 0.06$; balancing condition * rotation angle: F (2.16, 101.36) = 2.64, $p = .072$, $\eta^2_p = 0.05$) nor a significant three-way interaction between the factors task, balancing condition, and rotation angle (F (1.81, 85.27) = 0.65, $p = .509$, $\eta^2_p = 0.01$). Regarding the comparison between the control condition and the MBRTs, the ANOVA revealed a main effect of task (F (1.39, 65.39) = 0.48, $p = .004$, $\eta^2_p = 0.14$), showing that participants committed more errors in the object-based transformation task (1.6%), compared to the egocentric transformation task (0.5%) and the control condition (0%). Post-hoc t-test showed a significant difference between all tasks (all $p < .05$). There was no main effect for balancing condition (F (1, 47) = 0.33, $p = .569$, $\eta^2_p = 0.01$) nor a two-way interaction between the factors task and balancing condition (F (1.36, 63.57) = 0.26, $p = .681$, $\eta 2\ p = 0.01$).

Figure 3

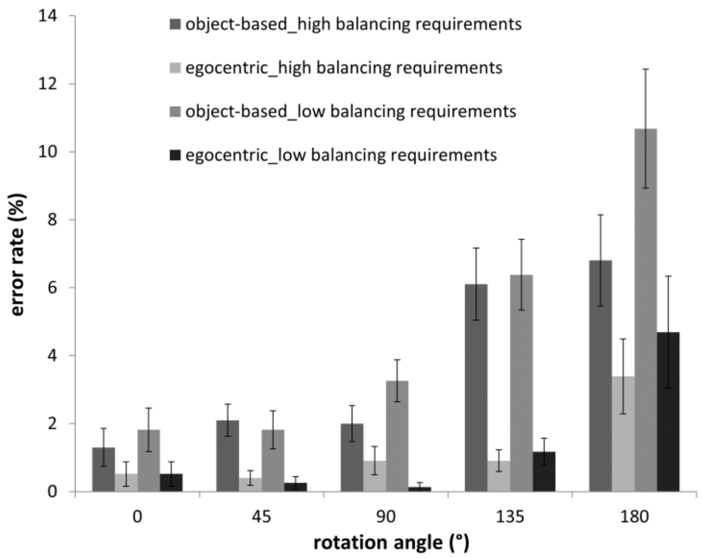
Results for Response Time (RT) in Experiment 1.



Note: The figure demonstrates the mean response time (RT) in milliseconds (SD) for the object-based transformation task and the egocentric transformation task in the two different balancing conditions.

Figure 4

Results for Response Error (RE) in Experiment 1.



Note: The figure demonstrates the mean response error (RE) in percentages (SD) for the object-based transformation task and the egocentric transformation task in the two different balancing conditions.

Discussion

The results of Experiment 1 are consistent with previous studies on mental body rotation: Response times and response errors increase for visual-spatial transformation the more the stimuli must be mentally rotated (e.g., Jansen, Lehman, & van Doren, 2012; Parsons, 1987; Steggemann et al., 2011). Also, participants performed better for egocentric perspective transformations than for object-based transformations (e.g., Budde et al., 2020, 2021; Jola & Mast, 2005; Kaltner et al., 2014; Pietsch & Jansen, 2018), as reflected in faster response times and fewer error rates. This supports the notion that aligning oneself with the person displayed is faster than to spatially align and compare two objects (Jola & Mast, 2005; Parsons, 1987). As in the previous studies of Budde et al. (2020, 2021), the results did not reveal a significant difference between the two balancing conditions (low requirements vs high requirements). The challenges to dynamic stability and thus, different demands on postural control do not seem to influence performance in the MBRT, neither for egocentric perspective transformation nor for object-based transformation, at least when participants are in active control over the perturbation. Our prediction, that the balancing condition (i.e., standing on a balance board vs. parallel stance on even ground) has an influence on the performance, was only reflected in the response errors. Here, the results showed that participants committed more errors when standing on even ground compared to when standing on a balance board. However, the error rates are rather low and the differences between the balancing conditions maybe only an artefact of the test population, as no such differences were found in the two previous studies of Budde et al. (2020, 2021). Moreover, for the control condition without mental rotation, there was no significant difference between high and low balancing requirements as well. The fact that participants did not make any mistake in the control condition suggests that this task was too easy and can be seen as a limitation of this study. From this pattern of results, it seems that manipulating the balancing position (i.e., standing posture) has no influence on the performance of a cognitive task, regardless of its difficulty (with or without mental rotation). If this, however, holds also true for conditions in which participants are required to perform under re-active balance control will be examined in Experiment 2.

Experiment 2: MBRT on a vibration plate

Experiment 2 examined the effect of re-active balance control, where perturbation is externally determined by a vibration plate (low and high intensities), on the performance (response time and response error) of healthy young people in a MBRT requiring a leftright judgment. Participants again watched images of a female person with either her left or right arm outstretched, which should induce an egocentric perspective transformation. Based on previous studies (e.g., Budde et al., 2021; Hofmann & Jansen, 2021), where a stabilization effect exclusively for the egocentric transformation task was found, only this task was part of the current experiment. In all studies mentioned before, participants performed under active balance control condition. For the first time, dynamic stability is challenged in another way in Experiment 2, namely with a re-active balance control condition (for the different requirements on the control of the dynamics of standing balance, see Balasubramaniam & Wing, 2002; Pollock et al., 2000). Therefore, the expectations regarding the effects of the different balancing requirements (low vs. high) are rather unspecific and it will be investigated exploratively if vibration intensity has an impact (positive, negative, or no impact) on mental rotation performance.

Method

Sample

A sample-size calculation by using the program “MorePower” (Version 6.0.4) was done to calculate the optimal sample size. We set the alpha-level to 0.05, power to 0.8 and the effect size (η^2_p) to 0.08. The program revealed a sample size of 32. Therefore, thirty-three sport science students (12 females and 20 males, mean age = 22.1 years, age range 19–28 years, 4 left-handers) with normal or corrected-to-normal vision took part in the experiment. All participants gave their informed consent prior to the experiment and none of them participated in a comparable mental rotation experiment for the last six month. They all received course credits, but there was no financial or other benefit for participation. The study was carried out in accordance with the Helsinki Declaration of 1975 and approved by the local ethics committee of the university.

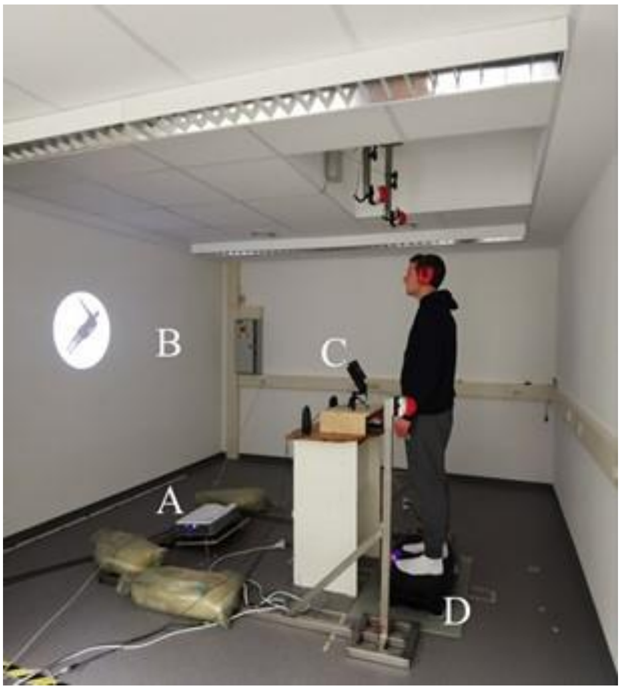
Apparatus

As in Experiment 1, a projector (Optoma) presented the stimuli onto a wall by using the software “Presentation” (Version 20.2, Neurobehavioral Systems). The stimuli size and the distance between the wall and the standing position were the same as in Experiment 1. Participants viewed the experimental stimuli standing on a vibration plate (Bluefin Fitness Vibration Plate

3D, 84x50x21cm) in a feet parallel position and verbal responses were given with a microphone (Rhode) linked via an usb-port with the computer. The experimental set-up can be seen from Fig. 5.

Figure 5

Experimental set-up of Experiment 2.



Note: Picture of the experimental set-up with the standing position on the vibration plate. A: projector, B: wall on which the stimuli were projected, C: microphone, D: vibration plate.

Stimulus material

A single image depicting a female person in back view with either the left or the right arm outstretched appeared on a black screen. Therefore, a left-right decision was required. The images and the rotation angles were the same as those of the egocentric perspective transformation task of Experiment 1 (see Fig. 2C-D).

Procedure and task

Participants were tested individually in the laboratory of the university. The test session lasted about 30 min. After filling out a short questionnaire and giving informed consent, participants read the standardized task instructions. To familiarize themselves with the task and the stimuli, participants performed a short practice session of 16 trials before the test blocks. For this practice session and for the first test block, the vibration plate was deactivated. The first test block served as the baseline condition (i.e., a vibration intensity of 0 Hz), in which participants performed without prior experience of different vibration conditions. After performing in the baseline condition, participants were tested under two more conditions, one with the vibration plate moving in horizontal direction (medial-lateral) with low frequency (20 Hz) and one with the vibration plate moving in horizontal direction (medial-lateral) with high frequency (180 Hz), respectively. The order of the two vibration conditions was counterbalanced across participants. There was a two-minute break between all test blocks. Each of the three test blocks consisted of a combination of rotation angle (clockwise 0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°) and arm outstretched (left arm vs. right arm). Each stimulus combination was presented five times per block, resulting in 80 trials in each block. Since each block was presented two times, the entire experiment consisted of 480 trials. Half of the trials showed the person raising the left arm and half of the trials displayed the person raising the right arm. The order of the presentation of the stimuli was randomized. Participants were instructed to judge as quickly and as accurate as possible whether the female's left or right arm was outstretched. They had to answer "links" (German word for "left") when the left arm was raised and to answer "rechts" (German word for "right") when the right arm was raised. Each trial started with a black screen for 500 ms followed by a white fixation cross for another 500 ms. The stimuli stayed on the screen until participants gave their answer. In case of a wrong answer, they received feedback and the word "Fehler" (German for "error") appeared on the screen for 1000 ms.

Data analysis

Data were analyzed within a two-way ANOVA, including the factors rotation angle (0°, 45°/315°, 90°/270°, 135°/225°, 180°) and vibration intensity (0, 20, 180 Hz) as repeated measures. Reaction times (RT) faster than 100 ms (0.01%) and slower than 2500 ms (1.87%) were excluded from statistical analysis. Data from incorrect trials (1.74%) were discarded from data analysis for RTs and instead, separately analyzed in another two-way ANOVA for response error (RE). Data from the practice sessions were not analyzed. The Greenhous-Geisser adjustment was used to correct for violations of sphericity and post-hoc t-test were Bonferroni-Holm adjusted.

Results

Response time (RT)

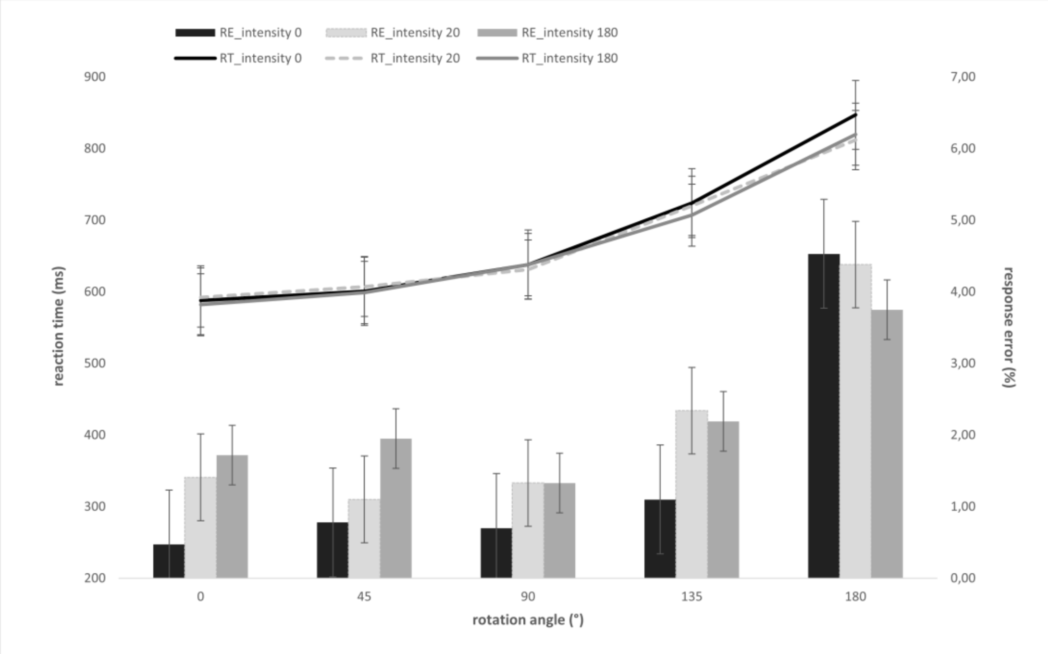
Fig. 6 (line graph) provides the RT pattern for the different rotation angles across the three vibration intensities. The ANOVA revealed a main effect of rotation angle F (1.8, 56.87) = 153.70, *p* < .001, η^2_p = 0.83, with the RT steadily increasing. Post-hoc t-test indicated that RT differed significantly for each angular disparity to the next proximate one (all *p* = .004), except for between 0° and 45° (*p* = .09). There was no main effect for vibration intensity (F (2, 62) = 0.92, *p* = .405, η^2_p = 0.03) and no significant two-way interaction between rotation angle and vibration intensity (F (4.04, 125.38) = 1.34, *p* = .259, η^2_p = 0.04).

Response error (RE)

The RE pattern for the different rotation angles across the three vibration intensities can be seen in Fig. 6 (bar graph). The ANOVA revealed a main effect for rotation angle (F (1.49, 46.31) = 13.54, *p* < .001, *η2 p* = 0.30). Post-hoc t-test showed that RE differed significant only between rotation angles 135° and 180° (*p* = .004). The ANOVA did not reveal a significant main effect for vibration intensity (F (1.45, 45.04) = 0.93, *p* = .375, η^2_p = 0.03) and no significant two-way interaction between the rotation angle and vibration intensity (F (3.60, 111.46) = 0.88, *p* = .472, η^2_p = 0.03).

Figure 6

Results for Response Time (RT) and Response Error (RE) in Experiment 2.



Note: The figure demonstrates the mean response time (RT; line graph) in milliseconds (SD) and the mean response error (RE; bar graph) in percentages (SD) for the egocentric transformation task for the three different intensities.

Discussion

Experiment 2 investigated the impact of different re-active balance control conditions induced by different vibration intensities from a vibration plate on the performance in a MBRT. The task required a left-right judgment, and participants had to decide whether a female person presented in back view raised her left or her right arm. The results show that response times and response errors increased the more the figure had to be mentally rotated, which is in line with previous studies on mental body-rotation (e.g., Budde et al., 2020, 2021; Jola & Mast, 2005; Kaltner et al., 2014; Pietsch & Jansen, 2018; Steggemann et al., 2011). However, there was no effect of the vibration intensity on participants' performance and therefore, the prediction, that participants performance would be better or worse when balancing requirements are challenged by higher vibration intensities, cannot be confirmed. In Experiment 2, as well as in previous studies (e.g., Budde et al., 2020, 2021) with active balance control, participants were similar able to map their own body representation to the presented figure when dynamic stability was challenged, indicating that different balancing requirements do not seem to influence performance in MBRT. Therefore, it can be concluded that embodied processes take no effect on participants' mental rotation performance, as there appears to be no interference between postural control processes (i.e., keeping balance on the vibration plate) and mental rotation (i.e., performing a mental body-rotation task).

General discussion

The present study aimed to examine the potential influence of different balancing conditions with low and high balancing requirements on the performance in MBRTs. Therefore, healthy young students performed in two MBRTs, one inducing an egocentric perspective transformation (left-right judgment; Experiment 1 and 2) and the other inducing an object-based transformation (same-different judgment; Experiment 1). In addition, and as a control condition, in Experiment 1 a color-naming task (blue and yellow circles) without any mental rotation was presented. In Experiment 1, it was expected that the same-different judgment would cause an object-based transformation and that the left-right judgment for a single image depicting a female person in back view with either the left or the right arm outstretched would induce an egocentric perspective transformation in the participants. Based on earlier findings on mental rotation (e.g., Budde et al., 2020, 2021; Jola & Mast, 2005; Kaltner et al., 2014; Pietsch & Jansen, 2018; Steggemann et al., 2011), it was assumed that participants perform better (as reflected in faster response times and fewer response errors) for egocentric perspective transformations than for object-based transformations. Across the two experiments, it was predicted that challenging dynamic stability in two different ways (active balance control and re-active balance control) would affect the performance in the two MBRTs: Performance differences between the balancing conditions were predicted in the MBRTs with left-right judgment and samedifferent judgment, favoring the balancing condition with higher balancing requirements on the balance board (active balancing, Experiment 1). Because it was the first time that the effects of re-active balance control on mental rotation were examined in Experiment 2, the predictions were unclear. It could be that such differences appear in the MBRT with left-right judgment, favoring the higher or the lower intensity, or that there are no differences between the balancing conditions.

In line with the predictions derived from previous studies on mental rotation (e.g., Budde et al., 2020, 2021; Jola & Mast, 2005; Kaltner et al., 2014; Pietsch & Jansen, 2018; Steggemann et al., 2011), the results show that response times and response errors increase for visual-spatial transformations of human bodies, the more the stimuli must be rotated. As predicted, the performance in the MBRT was better for egocentric perspective transformations than for object-based transformations. This supports the notion that aligning oneself into the person displayed is easier than to spatially align and compare two images (Jola & Mast, 2005; Parsons, 1987). In contrast to the notion that performance improves when dynamic stability was challenged (e.g., Bray et al., 2004; Kawasaki et al., 2014), the results revealed that the balancing condition in which participants solved the MBRTs did not lead to any effects on their mental rotation performance. This holds true for the active balancing condition in Experiment 1 (standing on even ground vs. standing on a balance board), as well as for a re-active balancing condition in Experiment 2 (no vibration vs. low vibration and high vibration). Moreover, this was also true for the control condition (Experiment 1) without any mental rotation. Therefore, it seems that it does not matter which kind of cognitive task is performed by the participants. The different balancing conditions (low vs high balancing requirements) do not influence the performance in these tasks.

With regards to the embodied cognition approach, which assumes that mental and motor processes cannot be separated from each other (Barsalou, 1999; Wexler, Kosslyn, & Berthoz, 1998; Wilson, 2002) and considering the study by Bray et al. (2004) on the perception of visual orientation, who found better performance of participants when postural control was challenged, this result is surprising. Nevertheless, it is in line with the findings of two previous studies (Budde et al., 2020, 2021), where challenges to dynamic stability and balance posture did not influence the performance in the MBRTs, i.e., participants were similarly able to solve the tasks while being tested in different balance positions. The only exception was in Experiment 1 when participants committed more mistakes while standing on even ground (low balancing requirements) compared to when standing on a balance board (high balancing requirements). However, this observation must be viewed with caution and should not be overinterpreted, because it was the only case where a difference between the balancing conditions was found across these studies (cf. Budde et al., 2020, 2021) and it may thus be an artefact of the present study sample in Experiment 1.

When participants perform under active balance control conditions, it has been demonstrated that performing a MBRT with an egocentric perspective transformation influences body sway parameters, as the CoP data reflected a reduction of body sway during this task, as compared to a MBRT with object-based transformations (e.g., Budde et al., 2021; Hofmann & Jansen, 2021). However, there seems to be no influence of the different active balance control conditions on the performance in MBRTs or other cognitive task, as measured with response times and response error rates (e.g., Budde et al., 2020, 2021). This was also true for the performance in the present Experiment 2 with another way to challenge dynamic stability, where perturbation was evoked by a moving vibration plate (re-active balance control, Experiment 2).

Taken together, the findings of Experiment 1 and Experiment 2 indicate that postural control processes do not interfere with perceptual-cognitive processes (i.e., performing mental body-rotation tasks) and therefore, embodied processes may not have influenced participants performance. This conclusion holds true for active balance control while sitting vs. standing (Budde et al., 2020), standing vs. balancing on a balancing beam (Budde et al., 2021), and standing vs. balancing on a balance board (the present Experiment 1). Moreover, it is also true for re-active balance control when comparing different intensities evoked by a vibration plate (the present Experiment 2). A limitation of all previous experiments is that only young and healthy (sport science) students performed in these different tasks. Maybe the challenges of dynamic stability were too easy for these participants and future studies could examine if there are comparable results when the tasks are performed by older adults or by children.

Conclusion

In summary, the present experiments were designed to investigate ones more the relation between dynamic stability and mental body rotation. The results revealed no influence of different balancing requirements on two different MBRTs when performing under active balance control (Experiment 1) and under re-active balance control (Experiment 2) conditions. There was no significant difference while performing a MBRT in a parallel standing position on even ground (low requirements) and while standing on a balance board (high requirements), nor while standing on a vibration platform with different vibration intensities.

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CRediT authorship contribution statement

Kirsten Budde: Conceptualization, Methodology, Software, Investigation, Formal analysis, Writing – original draft.

Matthias Weigelt: Conceptualization, Methodology, Writing – review & editing, Supervision.

Declaration of Competing Interest

None. The authors have no conflicts of interest to disclose.

Data availability

In accordance with the open science framework, we provide all data of the present two experiments here: https://osf.io/fhv94/.

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Appendix

A Study 1

A| 1.1 Consent form

UNIVERSITÄT PADERBORN
Die Universität der Informationsgesellschaft

Universität Paderborn
Warburger Str. 100
33098 Paderborn, Germany

Fakultät für Naturwissenschaft
Department Sport und Gesundheit
Arbeitsbereich Psychologie und Bewegung

Ansprechpartnerin: Kirsten Budde
Mail: kirsten.budde@uni-paderborn.de
Telefon: 0049 (0) 5251 60 - 5302

Datenschutzrechtliche Einwilligung und Aufklärung inkl. Information gem. Art.13 EU-DSGVO

Diese Datenschutzhinweise beschreiben die Verarbeitung personenbezogener Daten, die zu Forschungszwecken im Arbeitsbereich Psychologie und Bewegung (Fakultät für Naturwissenschaft, Universität Paderborn) erhoben werden.
Mit diesen Datenschutzhinweisen kommt die Universität Paderborn ihrer Informationspflicht gemäß Artikel 13 der EU-Datenschutzgrundverordnung (EU-DSGVO) nach.

1. Beschreibung des Forschungsvorhabens
In der Studie „Mentale Rotation im Stehen und im Sitzen“ werden den Probanden objekt-basierte und egozentrische Stimuli gezeigt. Die Probandin/der Proband soll schnellstmöglich auf diese Reize reagieren, wobei sie/er die Aufgaben sowohl im Stehen als auch im Sitzen durchführt. Das Experiment besteht aus einem Untersuchungstermin und dauert ca. 60 Minuten.

2. Inhalt und Zweck der Studie
In der Studie soll der Einfluss der Position (Stehen vs. Sitzen) auf die Mentale Rotationsleistung untersucht werden.

3. Datenaufzeichnung und Datenauswertung
Die Daten werden an der Universität Paderborn erhoben, ausgewertet und gespeichert. Im Rahmen des Forschungsvorhabens werden von gesunden, erwachsenen Teilnehmer/innen mittels Fragebogen personenbezogene Daten (Name, Mail-Adresse, Alter, Geschlecht, Händigkeit, Angaben zu Fehlsichtigkeit, Beruf und sportlicher Aktivität) erhoben. Zudem werden im Rahmen des oben beschriebenen Forschungsvorhabens Reaktionszeiten und Reaktionsfehler aufgezeichnet und ausgewertet. Die Aufzeichnung und Auswertung dieser Daten erfolgt pseudonymisiert, d. h. unter Verwendung einer Nummer und ohne Bezug zu ihren personenbezogenen Daten des Fragebogens. Es existiert eine Kodierliste auf Papier, die Ihren Namen mit dieser Nummer verbindet. Diese Kodierliste ist nur der Projektleitung und dem/der Versuchsleiter/in zugänglich und wird nach Abschluss der Datenauswertung gelöscht. **Die Weiterverarbeitung der Daten erfolgt vollständig anonymisiert.**

4. Lagerung und Weitergabe der Daten
Die Ergebnisse und Daten dieser Studie werden als wissenschaftliche Publikation veröffentlicht. Dies geschieht in anonymisierter Form, d. h. ohne dass die Daten einer spezifischen Person zugeordnet werden können. Die vollständig anonymisierten Daten dieser Studie werden ggf. als offene Daten im Internet in einem Datenarchiv zugänglich gemacht. Damit folgt diese Studie den Empfehlungen der Deutschen Forschungsgemeinschaft (DFG) und der Deutschen Gesellschaft für Psychologie (DGPs) zur Qualitätssicherung in der Forschung.

5. Rechtsgrundlagen

Die Rechtsgrundlage zur Verarbeitung der genannten personenbezogenen Daten bildet die Einwilligung gemäß Art. 6 (1) Buchstabe a EU-DSGVO.
Sie haben das Recht, jederzeit die datenschutzrechtliche Einwilligung zu widerrufen. Durch den Widerruf der Einwilligung wird die Rechtmäßigkeit der aufgrund der Einwilligung bis zum Widerruf erfolgten Verarbeitung nicht berührt (Widerruf mit Wirkung für die Zukunft). Richten Sie den Widerruf an den/die Verantwortliche/n. Ihnen entstehen durch den Widerruf keine Nachteile.
Nach Eingang des Widerrufs werden Ihre personenbezogenen Daten, sofern möglich, gelöscht (siehe nachfolgend „Recht auf Löschung").

Sie können als betroffene Person jederzeit die Ihnen durch die EU-DSGVO gewährten Rechte geltend machen:

- das Recht auf Auskunft, ob und welche Daten von Ihnen verarbeitet werden (Art. 15 DSGVO);
- das Recht, die Berichtigung oder Vervollständigung der Sie betreffenden Daten zu verlangen (Art. 16 DSGVO);
- das Recht auf Löschung der Sie betreffenden Daten nach Maßgabe des Art. 17 DSGVO. Wenn allerdings die Kodierliste bereits gelöscht ist (siehe 4.), kann Ihr Datensatz nicht mehr identifiziert und also auch nicht mehr gelöscht werden. Ihre Daten sind dann anonymisiert.
- das Recht, nach Maßgabe des Art. 18 DSGVO eine Einschränkung der Verarbeitung der Daten zu verlangen;
- das Recht auf Widerspruch gegen eine künftige Verarbeitung der Sie betreffenden Daten nach Maßgabe des Art. 21 DSGVO.

Möchten Sie eines dieser Rechte in Anspruch nehmen, dann wenden Sie sich bitte an den/die **Verantwortlichen des Forschungsvorhabens** (siehe Ansprechpartner im Briefkopf).

Verantwortlich für die Umsetzung der DSGVO ist die Universität Paderborn. Sie wird durch die Präsidentin/ den Präsidenten vertreten.
Die/den behördliche/n **Datenschutzbeauftragte/n** der Universität Paderborn erreichen Sie postalisch unter oben angegebener Adresse der/ des Verantwortlichen oder wie folgt:

E-Mail: datenschutz@uni-paderborn.de
Tel.: 05251 60-2400
http://www.uni-paderborn.de/datenschutz

Sie haben über die genannten Rechte hinaus das Recht, eine Beschwerde bei der datenschutzrechtlichen Aufsichtsbehörde einzureichen (Art. 77 DSGVO), zum Beispiel bei der/ dem für die Hochschule zuständigen

Landesbeauftragten für Datenschutz und Informationsfreiheit Nordrhein-Westfalen
Kavalleriestraße 2-4
40213 Düsseldorf
Telefon: 0211 38424-0
E-Mail: poststelle@ldi.nrw.de

6. Einwilligung In die Erhebung und Verarbeitung personenbezogener Daten

Hiermit willige ich freiwillig in die Erhebung und Verarbeitung meiner personenbezogenen Daten ein. Ich bin ausreichend informiert worden und hatte die Möglichkeit, Fragen zu stellen. Über die Folgen eines jederzeit möglichen Widerrufs der datenschutzrechtlichen Einwilligung bin ich aufgeklärt worden. Ich bin darüber informiert worden, dass durch meinen Widerruf der Einwilligung die Rechtmäßigkeit der aufgrund der Einwilligung bis zum Widerruf erfolgten Verarbeitung nicht berührt wird.
Die schriftliche Aufklärung und Einwilligung habe ich erhalten.

A| 1.2 Initial questionnaire

UNIVERSITÄT PADERBORN
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Arbeitsbereich Psychologie und Bewegung

Ansprechpartnerin: Kirsten Budde
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Telefon: 0049 (0) 5251 60 - 5302

Eingangsfragebogen

Studie: „Mentale Rotation im Stehen und im Sitzen“

Vpn-Nr.: ________ **Datum:** ________ **Uhrzeit:** ________

Alter: _________

Geschlecht: ( ) weiblich ( ) männlich

Beruf/Studiengang: _______________________

Sehvermögen: ( ) uneingeschränkt ( ) eingeschränkt (Dioptrien: ____________)
( ) kurzsichtig
( ) weitsichtig
( ) andere Einschränkungen: _____________
Die benötigte Sehhilfe/Korrektur wird bei der Untersuchung
( ) getragen ( ) nicht getragen

Haben Sie schon einmal an einer Untersuchung zur „Mentalen Rotation“ teilgenommen?
( ) ja, an folgender Untersuchung: ____________________________
( ) nein

Leiden Sie an einer neurologischen Erkrankung?
( ) ja, an folgender Erkrankung: ______________________________
( ) nein

Edinburgh Handedness Inventory (nach Oldfield, 1971)

Bitte geben Sie Ihre bevorzugte Hand bei den folgenden Tätigkeiten oder bei der Benutzung der aufgeführten Gegenstände an.

Tragen Sie ein „+“ in die Spalte LINKS oder RECHTS hinter der jeweiligen Tätigkeit ein, wenn Sie dabei die linke oder rechte Hand bevorzugen. Ist die Bevorzugung einer Hand so stark, dass Sie die andere niemals verwenden würden, tragen Sie bitte „++“ in das zugehörige Feld ein. Können Sie bei einer Tätigkeit wirklich keine bevorzugte Hand angeben, tragen Sie bitte ein „+“ in beide Felder hinter der Tätigkeit ein. Bei manchen Tätigkeiten oder der Benutzung der Gegenstände werden beide Hände benötigt. In diesen Fällen ist in Klammern angegeben, auf welche Tätigkeit sich die Frage genau bezieht.

Bitte versuchen Sie alle Fragen zu beantworten. Lassen Sie nur dann eine Tätigkeit aus, wenn Sie überhaupt keine Erfahrung damit haben.

		Links	**Rechts**
1	Schreiben		
2	Malen		
3	Werfen		
4	Schere		
5	Zähneputzen		
6	Messer (ohne Gabel)		
7	Löffel		
8	Besen (obere Hand)		
9	Streichholz anzünden (Streichholz)		
10	Dose öffnen (Deckel)		

LQ		Hier bitte nichts eintragen	Decile	

A| 1.3 Instruction object-based transformation task

Instruktion A

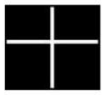
Liebe Probandin, lieber Proband,

bitte lies Dir die folgenden Informationen genau durch.

Dies ist ein REAKTIONSZEITEXPERIMENT!

Es geht also darum, so schnell wie möglich auf eine Reizdarbietung zu reagieren.

Im Folgenden wird Dir zunächst ein weißes Fixationskreuz gezeigt.



Es signalisiert Dir, dass es gleich losgeht.

Danach werden dir zwei nebeneinander angeordnete Bilder gezeigt.

Auf dem linken Bild siehst Du eine Person in aufrechter Position, die den linken oder den rechten Arm ausgestreckt hat.

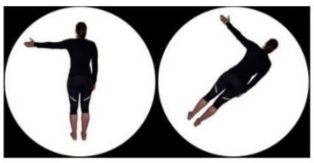
Auf dem rechten Bild ist eine Person in aufrechter Position oder in einem rotierten Winkel zu sehen, die entweder den gleichen Arm oder den anderen Arm ausgestreckt hat (also ein gespiegeltes Bild der linken Person).

Deine Aufgabe:

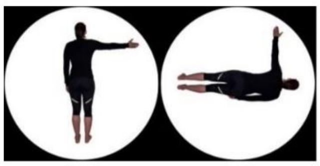
Entscheide schnellstmöglich, ob das Bild links identisch ist mit dem Bild daneben (d.h., dass beide Personen den gleichen Arm ausgestreckt haben).

Antworte laut und deutlich GLEICH, wenn die gezeigten Bilder identisch sind.

Antworte laut und deutlich UNGLEICH, wenn die gezeigten Bilder unterschiedlich sind.



Beispiel für identische Bilder
 richtige Antwort: **GLEICH**



Beispiel für unterschiedliche Bilder
 richtige Antwort: **UNGLEICH**

A| 1.4 Instruction egocentric transformation task

Instruktion B

Liebe Probandin, lieber Proband,

bitte lies Dir die folgenden Informationen genau durch.

Dies ist ein REAKTIONSZEITEXPERIMENT!

Es geht also darum, so schnell wie möglich auf eine Reizdarbietung zu reagieren.

Im Folgenden wird Dir zunächst ein weißes Fixationskreuz gezeigt.

Es signalisiert Dir, dass es gleich losgeht.

Danach wird Dir ein Bild gezeigt.

Darauf ist eine Person zu erkennen, die den linken oder den rechten Arm ausgestreckt hat. Die Person wird in aufrechter Position oder in einem rotierten Winkel dargestellt.

Deine Aufgabe:

Entscheide schnellstmöglich, welchen Arm die Person ausgestreckt hat.

Antworte laut und deutlich LINKS, wenn die Person den linken Arm ausgestreckt hat.

Antworte laut und deutlich RECHTS, wenn die Person den rechten Arm ausgestreckt hat.

Beispiel für rechten Arm
richtige Antwort: **RECHTS**

Beispiel für linken Arm
richtige Antwort: **LINKS**

B Study 2

B| 1.1 Consent form

UNIVERSITÄT PADERBORN
Die Universität der Informationsgesellschaft

Universität Paderborn
Warburger Str. 100
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Fakultät für Naturwissenschaft
Department Sport und Gesundheit
Arbeitsbereich Psychologie und Bewegung

Ansprechpartnerin: Kirsten Budde
Mail: kirsten.budde@uni-paderborn.de
Telefon: 0049 (0) 5251 60 - 5302

Datenschutzrechtliche Einwilligung und Aufklärung inkl. Information gem. Art.13 EU-DSGVO

Diese Datenschutzhinweise beschreiben die Verarbeitung personenbezogener Daten, die zu Forschungszwecken im Arbeitsbereich Psychologie und Bewegung (Fakultät für Naturwissenschaft, Universität Paderborn) erhoben werden.
Mit diesen Datenschutzhinweisen kommt die Universität Paderborn ihrer Informationspflicht gemäß Artikel 13 der EU-Datenschutzgrundverordnung (EU-DSGVO) nach.

1. Beschreibung des Forschungsvorhabens
In der Studie „Mentale Rotation von egozentrischen und objekt-basierten Stimuli beim Stehen auf dem Balancierbalken und Stehen auf der Kraftmessplatte" sollen die Probanden schnellstmöglich auf visuelle Reize reagieren. Die Antworten werden verbal mit Hilfe eines Mikrofons gegeben. Die Aufgaben werden im Stehen auf einer Kraftmessplatte und im Stehen auf einem Balancierbalken durchgeführt. Das Experiment besteht aus einem Untersuchungstermin und dauert ca. 45-60 Minuten.

2. Inhalt und Zweck der Studie
In der Studie soll der Zusammenhang zwischen der Mentalen Rotationsleistung und der posturalen Kontrolle untersucht werden. Es wird der Frage nachgegangen, ob die Position, in der die Aufgabe durchgeführt wird, einen Einfluss auf die Aufgabenausführung (Antwortzeiten, Antwortfehler) hat.

3. Datenaufzeichnung und Datenauswertung
Die Daten werden an der Universität Paderborn erhoben, ausgewertet und gespeichert. Im Rahmen des Forschungsvorhabens werden von gesunden, erwachsenen Teilnehmer/innen mittels Fragebogen personenbezogene Daten (Name, Mail-Adresse, Alter, Geschlecht, Händigkeit, Angaben zu Fehlsichtigkeit, Beruf und sportlicher Aktivität) erhoben. Zudem werden im Rahmen des oben beschriebenen Forschungsvorhabens Reaktionszeiten, Reaktionsfehler und Daten der Kraftmessplatte aufgezeichnet und ausgewertet. Die Aufzeichnung und Auswertung dieser Daten erfolgt pseudonymisiert, d. h. unter Verwendung einer Nummer und ohne Bezug zu ihren personenbezogenen Daten des Fragebogens. Es existiert eine Kodierliste auf Papier, die Ihren Namen mit dieser Nummer verbindet. Diese Kodierliste ist nur der Projektleitung und dem/der Versuchsleiter/in zugänglich und wird nach Abschluss der Datenauswertung gelöscht. **Die Weiterverarbeitung der Daten erfolgt vollständig anonymisiert.**

4. Lagerung und Weitergabe der Daten
Die Ergebnisse und Daten dieser Studie werden als wissenschaftliche Publikation veröffentlicht. Dies geschieht in anonymisierter Form, d. h. ohne dass die Daten einer spezifischen Person zugeordnet werden können. Die vollständig anonymisierten Daten dieser Studie werden ggf. als offene Daten im Internet in einem Datenarchiv zugänglich gemacht. Damit folgt diese Studie den Empfehlungen der Deutschen Forschungsgemeinschaft (DFG) und der Deutschen Gesellschaft für Psychologie (DGPs) zur Qualitätssicherung in der Forschung.

5. Rechtsgrundlagen

Die Rechtsgrundlage zur Verarbeitung der genannten personenbezogenen Daten bildet die Einwilligung gemäß Art. 6 (1) Buchstabe a EU-DSGVO.
Sie haben das Recht, jederzeit die datenschutzrechtliche Einwilligung zu widerrufen. Durch den Widerruf der Einwilligung wird die Rechtmäßigkeit der aufgrund der Einwilligung bis zum Widerruf erfolgten Verarbeitung nicht berührt (Widerruf mit Wirkung für die Zukunft). Richten Sie den Widerruf an den/die Verantwortliche/n. Ihnen entstehen durch den Widerruf keine Nachteile.
Nach Eingang des Widerrufs werden Ihre personenbezogenen Daten, sofern möglich, gelöscht (siehe nachfolgend „Recht auf Löschung").

Sie können als betroffene Person jederzeit die Ihnen durch die EU-DSGVO gewährten Rechte geltend machen:

- das Recht auf Auskunft, ob und welche Daten von Ihnen verarbeitet werden (Art. 15 DSGVO);
- das Recht, die Berichtigung oder Vervollständigung der Sie betreffenden Daten zu verlangen (Art. 16 DSGVO);
- das Recht auf Löschung der Sie betreffenden Daten nach Maßgabe des Art. 17 DSGVO. Wenn allerdings die Kodierliste bereits gelöscht ist (siehe 4.), kann Ihr Datensatz nicht mehr identifiziert und also auch nicht mehr gelöscht werden. Ihre Daten sind dann anonymisiert.
- das Recht, nach Maßgabe des Art. 18 DSGVO eine Einschränkung der Verarbeitung der Daten zu verlangen;
- das Recht auf Widerspruch gegen eine künftige Verarbeitung der Sie betreffenden Daten nach Maßgabe des Art. 21 DSGVO.

Möchten Sie eines dieser Rechte in Anspruch nehmen, dann wenden Sie sich bitte an den/die **Verantwortlichen des Forschungsvorhabens** (siehe Ansprechpartner im Briefkopf).

Verantwortlich für die Umsetzung der DSGVO ist die Universität Paderborn. Sie wird durch die Präsidentin/ den Präsidenten vertreten.
Die/den behördliche/n **Datenschutzbeauftragte/n** der Universität Paderborn erreichen Sie postalisch unter oben angegebener Adresse der/ des Verantwortlichen oder wie folgt:

E-Mail: datenschutz@uni-paderborn.de
Tel.: 05251 60-2400
http://www.uni-paderborn.de/datenschutz

Sie haben über die genannten Rechte hinaus das Recht, eine Beschwerde bei der datenschutzrechtlichen Aufsichtsbehörde einzureichen (Art. 77 DSGVO), zum Beispiel bei der/ dem für die Hochschule zuständigen

Landesbeauftragten für Datenschutz und Informationsfreiheit Nordrhein-Westfalen
Kavalleriestraße 2-4
40213 Düsseldorf
Telefon: 0211 38424-0
E-Mail: poststelle@ldi.nrw.de

6. Einwilligung In die Erhebung und Verarbeitung personenbezogener Daten

Hiermit willige ich freiwillig in die Erhebung und Verarbeitung meiner personenbezogenen Daten ein. Ich bin ausreichend informiert worden und hatte die Möglichkeit, Fragen zu stellen. Über die Folgen eines jederzeit möglichen Widerrufs der datenschutzrechtlichen Einwilligung bin ich aufgeklärt worden. Ich bin darüber informiert worden, dass durch meinen Widerruf der Einwilligung die Rechtmäßigkeit der aufgrund der Einwilligung bis zum Widerruf erfolgten Verarbeitung nicht berührt wird.
Die schriftliche Aufklärung und Einwilligung habe ich erhalten.

B| 1.2 Initial questionnaire

UNIVERSITÄT PADERBORN
Die Universität der Informationsgesellschaft

Universität Paderborn
Warburger Str. 100
33098 Paderborn, Germany

Fakultät für Naturwissenschaft
Department Sport und Gesundheit
Arbeitsbereich Psychologie und Bewegung

Ansprechpartnerin: Kirsten Budde
Mail: kirsten.budde@uni-paderborn.de
Telefon: 0049 (0) 5251 60 - 5302

Eingangsfragebogen

Studie: Mentale Rotation von egozentrischen und objekt-basierten Stimuli beim „Stehen auf dem Balancierbalken" & „Stehen auf der Kraftmessplatte"

Vpn-Nr.: ________	**Datum:** ___________	**Uhrzeit:** __________

Alter: _________ **Größe (cm):** _____________ **Gewicht (kg):** ____________

Geschlecht: ( ) weiblich ( ) männlich

Händigkeit: ( ) links ( ) rechts

Beruf/Studiengang: ____

Sehvermögen: ( ) uneingeschränkt ( ) eingeschränkt
( ) kurzsichtig ( ) weitsichtig
benötigte Sehhilfe/Korrektur bei der Untersuchung
( ) getragen ( ) nicht getragen
sonstige Augenerkrankungen: ____________________________________

Leiden Sie an einer neurologischen Erkrankung?
( ) ja, an folgender Erkrankung: _______________________________
( ) nein

Sportliche Tätigkeiten, die Sie regelmäßig betreiben bzw. betrieben haben:
Sportart: ______________________ von/bis (Jahr) ______________ Std./Woche: ____
Sportart: ______________________ von/bis (Jahr) ______________ Std./Woche: ____
Sportart: ______________________ von/bis (Jahr) ______________ Std./Woche: ____

Haben Sie schon einmal an einer Untersuchung zur „Mentalen Rotation" teilgenommen?
( ) ja, an folgender Untersuchung: ____________________________
( ) nein

B| 1.3 Instruction object-based transformation task

Instruktion A

Liebe Probandin, lieber Proband,

bitte lies Dir die folgenden Informationen genau durch.

Dies ist ein REAKTIONSZEITEXPERIMENT!

Es geht also darum, so schnell wie möglich auf eine Reizdarbietung zu reagieren.

Im Folgenden wird Dir zunächst ein weißes Fixationskreuz gezeigt.

Es signalisiert Dir, dass es gleich losgeht.

Danach werden dir zwei nebeneinander angeordnete Bilder gezeigt.

Auf dem linken Bild siehst Du eine Person in aufrechter Position, die den linken oder den rechten Arm ausgestreckt hat.

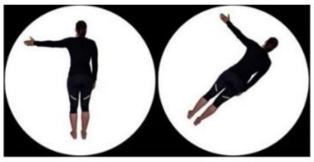
Auf dem rechten Bild ist eine Person in aufrechter Position oder in einem rotierten Winkel zu sehen, die entweder den gleichen Arm oder den anderen Arm ausgestreckt hat (also ein gespiegeltes Bild der linken Person).

Deine Aufgabe:

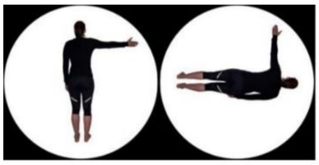
Entscheide schnellstmöglich, ob das Bild links identisch ist mit dem Bild daneben (d.h., dass beide Personen den gleichen Arm ausgestreckt haben).

Antworte laut und deutlich GLEICH, wenn die gezeigten Bilder identisch sind.

Antworte laut und deutlich UNGLEICH, wenn die gezeigten Bilder unterschiedlich sind.



Beispiel für identische Bilder
 richtige Antwort: **GLEICH**



Beispiel für unterschiedliche Bilder
 richtige Antwort: **UNGLEICH**

Deine Positionen:

Stehen: ohne Schuhe, enger Stand, mittig auf der Kraftmessplatte, Oberkörper aufrecht, Arme locker neben dem Körper hängen lassen

Balancierbalken: ohne Schuhe, Füße voreinander, Oberkörper aufrecht, Arme locker neben dem Körper hängen lassen

B| 1.4 Instruction egocentric transformation task

Instruktion B

Liebe Probandin, lieber Proband,

bitte lies Dir die folgenden Informationen genau durch.

Dies ist ein REAKTIONSZEITEXPERIMENT!

Es geht also darum, so schnell wie möglich auf eine Reizdarbietung zu reagieren.

Im Folgenden wird Dir zunächst ein weißes Fixationskreuz gezeigt.

Es signalisiert Dir, dass es gleich losgeht.

Danach wird Dir ein Bild gezeigt.

Darauf ist eine Person zu erkennen, die den linken oder den rechten Arm ausgestreckt hat. Die Person wird in aufrechter Position oder in einem rotierten Winkel dargestellt.

Deine Aufgabe:

Entscheide schnellstmöglich, welchen Arm die Person ausgestreckt hat.

Antworte laut und deutlich LINKS, wenn die Person den linken Arm ausgestreckt hat.

Antworte laut und deutlich RECHTS, wenn die Person den rechten Arm ausgestreckt hat.

Beispiel für rechten Arm
richtige Antwort: **RECHTS**

Beispiel für linken Arm
richtige Antwort: **LINKS**

Deine Positionen:

Stehen: ohne Schuhe, enger Stand, mittig auf der Kraftmessplatte, Oberkörper aufrecht, Arme locker neben dem Körper hängen lassen

Balancierbalken: ohne Schuhe, Füße voreinander, Oberkörper aufrecht, Arme locker neben dem Körper hängen lassen

B| 1.5 Instruction color-naming task

Instruktion C

Liebe Probandin, lieber Proband,

bitte lies Dir die folgenden Informationen genau durch.

Dies ist ein REAKTIONSZEITEXPERIMENT!

Es geht also darum, so schnell wie möglich auf eine Reizdarbietung zu reagieren.

Im Folgenden wird Dir zunächst ein weißes Fixationskreuz gezeigt.

Es signalisiert Dir, dass es gleich losgeht.

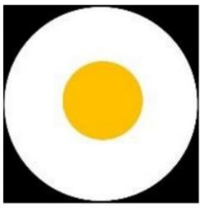
Danach wird dir ein Bild gezeigt, auf dem ein blauer oder ein gelber Kreis zu erkennen ist.

Deine Aufgabe:

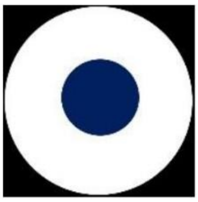
Entscheide schnellstmöglich, welche Farbe der Kreis hat.

Antworte laut und deutlich BLAU, wenn der Kreis blau eingefärbt ist.

Antworte laut und deutlich GELB, wenn der Kreis gelb eingefärbt ist



Beispiel für gelben Kreis
richtige Antwort: **GELB**



Beispiel für blauen Kreis
richtige Antwort: **BLAU**

Deine Positionen:

Stehen: ohne Schuhe, enger Stand, mittig auf der Kraftmessplatte, Oberkörper aufrecht, Arme locker neben dem Körper hängen lassen

Balancierbalken: ohne Schuhe, Füße voreinander, Oberkörper aufrecht, Arme locker neben dem Körper hängen lassen

C Study 3 – Experiment 1

C| 1.1 Consent form

UNIVERSITÄT PADERBORN
Die Universität der Informationsgesellschaft

Universität Paderborn
Warburger Str. 100
33098 Paderborn, Germany

Fakultät für Naturwissenschaft
Department Sport und Gesundheit
Arbeitsbereich Psychologie und Bewegung

Ansprechpartnerin: Kirsten Budde
Mail: kirsten.budde@uni-paderborn.de
Telefon: 0049 (0) 5251 60 - 5302

Datenschutzrechtliche Einwilligung und Aufklärung inkl. Information gem. Art.13 EU-DSGVO

Diese Datenschutzhinweise beschreiben die Verarbeitung personenbezogener Daten, die zu Forschungszwecken im Arbeitsbereich Psychologie und Bewegung (Fakultät für Naturwissenschaft, Universität Paderborn) erhoben werden.
Mit diesen Datenschutzhinweisen kommt die Universität Paderborn ihrer Informationspflicht gemäß Artikel 13 der EU-Datenschutzgrundverordnung (EU-DSGVO) nach.

1. Beschreibung des Forschungsvorhabens
In der Studie „Mentale Rotation von egozentrischen und objekt-basierten Stimuli beim Stehen auf dem Balancierkreisel und Stehen auf der Kraftmessplatte“ sollen die Probanden schnellstmöglich auf visuelle Reize reagieren. Die Antworten werden verbal mit Hilfe eines Mikrofons gegeben. Die Aufgaben werden im Stehen auf einer Kraftmessplatte und im Stehen auf einem Balancierkreisel durchgeführt. Das Experiment besteht aus einem Untersuchungstermin und dauert ca. 45-60 Minuten.

2. Inhalt und Zweck der Studie
In der Studie soll der Zusammenhang zwischen der Mentalen Rotationsleistung und der posturalen Kontrolle untersucht werden. Es wird der Frage nachgegangen, ob die Position, in der die Aufgabe durchgeführt wird, einen Einfluss auf die Aufgabenausführung (Antwortzeiten, Antwortfehler) hat.

3. Datenaufzeichnung und Datenauswertung
Die Daten werden an der Universität Paderborn erhoben, ausgewertet und gespeichert. Im Rahmen des Forschungsvorhabens werden von gesunden, erwachsenen Teilnehmer/innen mittels Fragebogen personenbezogene Daten (Name, Mail-Adresse, Alter, Geschlecht, Händigkeit, Angaben zu Fehlsichtigkeit, Beruf und sportlicher Aktivität) erhoben. Zudem werden im Rahmen des oben beschriebenen Forschungsvorhabens Reaktionszeiten, Reaktionsfehler und Daten der Kraftmessplatte aufgezeichnet und ausgewertet. Die Aufzeichnung und Auswertung dieser Daten erfolgt pseudonymisiert, d. h. unter Verwendung einer Nummer und ohne Bezug zu ihren personenbezogenen Daten des Fragebogens. Es existiert eine Kodierliste auf Papier, die Ihren Namen mit dieser Nummer verbindet. Diese Kodierliste ist nur der Projektleitung und dem/der Versuchsleiter/in zugänglich und wird nach Abschluss der Datenauswertung gelöscht. **Die Weiterverarbeitung der Daten erfolgt vollständig anonymisiert.**

4. Lagerung und Weitergabe der Daten
Die Ergebnisse und Daten dieser Studie werden als wissenschaftliche Publikation veröffentlicht. Dies geschieht in anonymisierter Form, d. h. ohne dass die Daten einer spezifischen Person zugeordnet werden können. Die vollständig anonymisierten Daten dieser Studie werden ggf. als offene Daten im Internet in einem Datenarchiv zugänglich gemacht. Damit folgt diese Studie den Empfehlungen der Deutschen Forschungsgemeinschaft (DFG) und der Deutschen Gesellschaft für Psychologie (DGPs) zur Qualitätssicherung in der Forschung.

5. Rechtsgrundlagen
Die Rechtsgrundlage zur Verarbeitung der genannten personenbezogenen Daten bildet die Einwilligung gemäß Art. 6 (1) Buchstabe a EU-DSGVO.
Sie haben das Recht, jederzeit die datenschutzrechtliche Einwilligung zu widerrufen. Durch den Widerruf der Einwilligung wird die Rechtmäßigkeit der aufgrund der Einwilligung bis zum Widerruf erfolgten Verarbeitung nicht berührt (Widerruf mit Wirkung für die Zukunft). Richten Sie den Widerruf an den/die Verantwortliche/n. Ihnen entstehen durch den Widerruf keine Nachteile.
Nach Eingang des Widerrufs werden Ihre personenbezogenen Daten, sofern möglich, gelöscht (siehe nachfolgend „Recht auf Löschung").

Sie können als betroffene Person jederzeit die Ihnen durch die EU-DSGVO gewährten Rechte geltend machen:

- das Recht auf Auskunft, ob und welche Daten von Ihnen verarbeitet werden (Art. 15 DSGVO);
- das Recht, die Berichtigung oder Vervollständigung der Sie betreffenden Daten zu verlangen (Art. 16 DSGVO);
- das Recht auf Löschung der Sie betreffenden Daten nach Maßgabe des Art. 17 DSGVO. Wenn allerdings die Kodierliste bereits gelöscht ist (siehe 4.), kann Ihr Datensatz nicht mehr identifiziert und also auch nicht mehr gelöscht werden. Ihre Daten sind dann anonymisiert.
- das Recht, nach Maßgabe des Art. 18 DSGVO eine Einschränkung der Verarbeitung der Daten zu verlangen;
- das Recht auf Widerspruch gegen eine künftige Verarbeitung der Sie betreffenden Daten nach Maßgabe des Art. 21 DSGVO.

Möchten Sie eines dieser Rechte in Anspruch nehmen, dann wenden Sie sich bitte an den/die **Verantwortlichen des Forschungsvorhabens** (siehe Ansprechpartner im Briefkopf).

Verantwortlich für die Umsetzung der DSGVO ist die Universität Paderborn. Sie wird durch die Präsidentin/ den Präsidenten vertreten.
Die/den behördliche/n **Datenschutzbeauftragte/n** der Universität Paderborn erreichen Sie postalisch unter oben angegebener Adresse der/ des Verantwortlichen oder wie folgt:

E-Mail: datenschutz@uni-paderborn.de
Tel.: 05251 60-2400
http://www.uni-paderborn.de/datenschutz

Sie haben über die genannten Rechte hinaus das Recht, eine Beschwerde bei der datenschutzrechtlichen Aufsichtsbehörde einzureichen (Art. 77 DSGVO), zum Beispiel bei der/ dem für die Hochschule zuständigen

Landesbeauftragten für Datenschutz und Informationsfreiheit Nordrhein-Westfalen
Kavalleriestraße 2-4
40213 Düsseldorf
Telefon: 0211 38424-0
E-Mail: poststelle@ldi.nrw.de

6. Einwilligung In die Erhebung und Verarbeitung personenbezogener Daten
Hiermit willige ich freiwillig in die Erhebung und Verarbeitung meiner personenbezogenen Daten ein. Ich bin ausreichend informiert worden und hatte die Möglichkeit, Fragen zu stellen. Über die Folgen eines jederzeit möglichen Widerrufs der datenschutzrechtlichen Einwilligung bin ich aufgeklärt worden. Ich bin darüber informiert worden, dass durch meinen Widerruf der Einwilligung die Rechtmäßigkeit der aufgrund der Einwilligung bis zum Widerruf erfolgten Verarbeitung nicht berührt wird.
Die schriftliche Aufklärung und Einwilligung habe ich erhalten.

C| 1.2 Initial questionnaire

UNIVERSITÄT PADERBORN
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Universität Paderborn
Warburger Str. 100
33098 Paderborn, Germany

Fakultät für Naturwissenschaft
Department Sport und Gesundheit
Arbeitsbereich Psychologie und Bewegung

Ansprechpartnerin: Kirsten Budde
Mail: kirsten.budde@uni-paderborn.de
Telefon: 0049 (0) 5251 60 - 5302

Eingangsfragebogen

Studie: Mentale Rotation von egozentrischen und objekt-basierten Stimuli beim „Stehen auf dem Balancierkreisel" & „Stehen auf der Kraftmessplatte"

Vpn-Nr.: ________ **Datum:** ___________ **Uhrzeit:** __________

Alter: _________ **Größe (cm):** _____________ **Gewicht (kg):** ____________

Geschlecht: ( ) weiblich ( ) männlich

Händigkeit: ( ) links ( ) rechts

Beruf/Studiengang: ____

Sehvermögen: ( ) uneingeschränkt ( ) eingeschränkt
( ) kurzsichtig ( ) weitsichtig
benötigte Sehhilfe/Korrektur bei der Untersuchung
( ) getragen ( ) nicht getragen
sonstige Augenerkrankungen: ___________________________________

Leiden Sie an einer neurologischen Erkrankung?
( ) ja, an folgender Erkrankung: ______________________________
( ) nein

Sportliche Tätigkeiten, die Sie regelmäßig betreiben bzw. betrieben haben:
Sportart: ______________________ von/bis (Jahr) ______________ Std./Woche: ____
Sportart: ______________________ von/bis (Jahr) ______________ Std./Woche: ____
Sportart: ______________________ von/bis (Jahr) ______________ Std./Woche: ____

Haben Sie schon einmal an einer Untersuchung zur „Mentalen Rotation" teilgenommen?
( ) ja, an folgender Untersuchung: ____________________________
( ) nein

C| 1.3 Instruction object-based transformation task

Instruktion A

Liebe Probandin, lieber Proband,

bitte lies Dir die folgenden Informationen genau durch.

Dies ist ein REAKTIONSZEITEXPERIMENT!

Es geht also darum, so schnell wie möglich auf eine Reizdarbietung zu reagieren.

Im Folgenden wird Dir zunächst ein weißes Fixationskreuz gezeigt.

Es signalisiert Dir, dass es gleich losgeht.

Danach werden dir zwei nebeneinander angeordnete Bilder gezeigt.

Auf dem linken Bild siehst Du eine Person in aufrechter Position, die den linken oder den rechten Arm ausgestreckt hat.

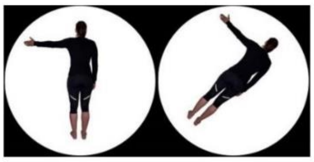
Auf dem rechten Bild ist eine Person in aufrechter Position oder in einem rotierten Winkel zu sehen, die entweder den gleichen Arm oder den anderen Arm ausgestreckt hat (also ein gespiegeltes Bild der linken Person).

Deine Aufgabe:

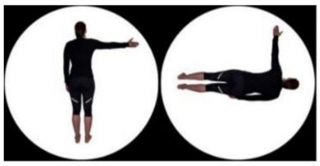
Entscheide schnellstmöglich, ob das Bild links identisch ist mit dem Bild daneben (d.h., dass beide Personen den gleichen Arm ausgestreckt haben).

Antworte laut und deutlich GLEICH, wenn die gezeigten Bilder identisch sind.

Antworte laut und deutlich UNGLEICH, wenn die gezeigten Bilder unterschiedlich sind.



Beispiel für identische Bilder
 richtige Antwort: **GLEICH**



Beispiel für unterschiedliche Bilder
 richtige Antwort: **UNGLEICH**

Deine Positionen:

Stehen: ohne Schuhe, enger Stand, mittig auf der Kraftmessplatte, Oberkörper aufrecht, Arme locker neben dem Körper hängen lassen

Balancierkreisel: ohne Schuhe, beide Füße auf den Kreisel, Oberkörper aufrecht, Arme locker neben dem Körper hängen lassen

C| 1.4 Instruction egocentric transformation task

Instruktion B

Liebe Probandin, lieber Proband,

bitte lies Dir die folgenden Informationen genau durch.

Dies ist ein REAKTIONSZEITEXPERIMENT!

Es geht also darum, so schnell wie möglich auf eine Reizdarbietung zu reagieren.

Im Folgenden wird Dir zunächst ein weißes Fixationskreuz gezeigt.

Es signalisiert Dir, dass es gleich losgeht.

Danach wird Dir ein Bild gezeigt.

Darauf ist eine Person zu erkennen, die den linken oder den rechten Arm ausgestreckt hat. Die Person wird in aufrechter Position oder in einem rotierten Winkel dargestellt.

Deine Aufgabe:

Entscheide schnellstmöglich, welchen Arm die Person ausgestreckt hat.

Antworte laut und deutlich LINKS, wenn die Person den linken Arm ausgestreckt hat.

Antworte laut und deutlich RECHTS, wenn die Person den rechten Arm ausgestreckt hat.

Beispiel für rechten Arm
richtige Antwort: **RECHTS**

Beispiel für linken Arm
richtige Antwort: **LINKS**

Deine Positionen:

Stehen: ohne Schuhe, enger Stand, mittig auf der Kraftmessplatte, Oberkörper aufrecht, Arme locker neben dem Körper hängen lassen

Balancierkreisel: ohne Schuhe, beide Füße auf den Kreisel, Oberkörper aufrecht, Arme locker neben dem Körper hängen lassen

C| 1.5 Instruction color-naming task

Instruktion C

Liebe Probandin, lieber Proband,

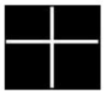
bitte lies Dir die folgenden Informationen genau durch.

Dies ist ein REAKTIONSZEITEXPERIMENT!

Es geht also darum, so schnell wie möglich auf eine Reizdarbietung zu reagieren.

Im Folgenden wird Dir zunächst ein weißes Fixationskreuz gezeigt.

Es signalisiert Dir, dass es gleich losgeht.



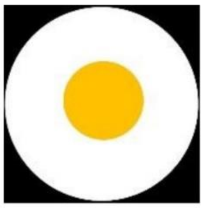
Danach wird dir ein Bild gezeigt, auf dem ein blauer oder ein gelber Kreis zu erkennen ist.

Deine Aufgabe:

Entscheide schnellstmöglich, welche Farbe der Kreis hat.

Antworte laut und deutlich BLAU, wenn der Kreis blau eingefärbt ist.

Antworte laut und deutlich GELB, wenn der Kreis gelb eingefärbt ist



Beispiel für gelben Kreis
richtige Antwort: **GELB**

Beispiel für blauen Kreis
richtige Antwort: **BLAU**

Deine Positionen:

Stehen: ohne Schuhe, enger Stand, mittig auf der Kraftmessplatte, Oberkörper aufrecht, Arme locker neben dem Körper hängen lassen

Balancierkreisel: ohne Schuhe, beide Füße auf den Kreisel, Oberkörper aufrecht, Arme locker neben dem Körper hängen lassen

D Study 3 – Experiment 2

D| 1.1 Consent form

UNIVERSITÄT PADERBORN
Die Universität der Informationsgesellschaft

Universität Paderborn
Warburger Str. 100
33098 Paderborn, Germany

Fakultät für Naturwissenschaft
Department Sport und Gesundheit
Arbeitsbereich Psychologie und Bewegung

Ansprechpartnerin: Kirsten Budde
Mail: kirsten.budde@uni-paderborn.de
Telefon: 0049 (0) 5251 60 - 5302

Datenschutzrechtliche Einwilligung und Aufklärung inkl. Information gem. Art.13 EU-DSGVO

Diese Datenschutzhinweise beschreiben die Verarbeitung personenbezogener Daten, die zu Forschungszwecken im Arbeitsbereich Psychologie und Bewegung (Fakultät für Naturwissenschaft, Universität Paderborn) erhoben werden.
Mit diesen Datenschutzhinweisen kommt die Universität Paderborn ihrer Informationspflicht gemäß Artikel 13 der EU-Datenschutzgrundverordnung (EU-DSGVO) nach.

1. Beschreibung des Forschungsvorhabens
In der Studie „Mentale Rotation von egozentrischen Stimuli beim Stehen auf einer Vibrationsplatte" sollen die Probanden schnellstmöglich auf visuelle Reize reagieren. Die Antworten werden verbal mit Hilfe eines Mikrofons gegeben. Die Aufgaben werden im Stehen auf einer Vibrationsplatte der Marke Bluefin durchgeführt. Das Experiment besteht aus einem Untersuchungstermin und dauert ca. 45-60 Minuten.

2. Inhalt und Zweck der Studie
In der Studie soll der Zusammenhang zwischen der Mentalen Rotationsleistung und dem statischen Gleichgewicht untersucht werden. Es wird der Frage nachgegangen, ob unterschiedliche Intensitätsstufen einen Einfluss auf die Aufgabenausführung (Antwortzeiten, Antwortfehler) haben.

3. Datenaufzeichnung und Datenauswertung
Die Daten werden an der Universität Paderborn erhoben, ausgewertet und gespeichert. Im Rahmen des Forschungsvorhabens werden von gesunden, erwachsenen Teilnehmer/innen mittels Fragebogen personenbezogene Daten (Name, Mail-Adresse, Alter, Geschlecht, Händigkeit, Angaben zu Fehlsichtigkeit, Beruf und sportlicher Aktivität) erhoben. Zudem werden im Rahmen des oben beschriebenen Forschungsvorhabens Reaktionszeiten und Reaktionsfehler aufgezeichnet und ausgewertet. Die Aufzeichnung und Auswertung dieser Daten erfolgt pseudonymisiert, d. h. unter Verwendung einer Nummer und ohne Bezug zu Ihren personenbezogenen Daten des Fragebogens. Es existiert eine Kodierliste auf Papier, die Ihren Namen mit dieser Nummer verbindet. Diese Kodierliste ist nur der Projektleitung und dem/der Versuchsleiter/in zugänglich und wird nach Abschluss der Datenauswertung gelöscht. **Die Weiterverarbeitung der Daten erfolgt vollständig anonymisiert.**

4. Lagerung und Weitergabe der Daten
Die Ergebnisse und Daten dieser Studie werden als wissenschaftliche Publikation veröffentlicht. Dies geschieht in anonymisierter Form, d. h. ohne dass die Daten einer spezifischen Person zugeordnet werden können. Die vollständig anonymisierten Daten dieser Studie werden ggf. als offene Daten im Internet in einem Datenarchiv zugänglich gemacht. Damit folgt diese Studie den Empfehlungen der Deutschen Forschungsgemeinschaft (DFG) und der Deutschen Gesellschaft für Psychologie (DGPs) zur Qualitätssicherung in der Forschung.

5. Rechtsgrundlagen

Die Rechtsgrundlage zur Verarbeitung der genannten personenbezogenen Daten bildet die Einwilligung gemäß Art. 6 (1) Buchstabe a EU-DSGVO.
Sie haben das Recht, jederzeit die datenschutzrechtliche Einwilligung zu widerrufen. Durch den Widerruf der Einwilligung wird die Rechtmäßigkeit der aufgrund der Einwilligung bis zum Widerruf erfolgten Verarbeitung nicht berührt (Widerruf mit Wirkung für die Zukunft). Richten Sie den Widerruf an den/die Verantwortliche/n. Ihnen entstehen durch den Widerruf keine Nachteile.
Nach Eingang des Widerrufs werden Ihre personenbezogenen Daten, sofern möglich, gelöscht (siehe nachfolgend „Recht auf Löschung").

Sie können als betroffene Person jederzeit die Ihnen durch die EU-DSGVO gewährten Rechte geltend machen:

- das Recht auf Auskunft, ob und welche Daten von Ihnen verarbeitet werden (Art. 15 DSGVO);
- das Recht, die Berichtigung oder Vervollständigung der Sie betreffenden Daten zu verlangen (Art. 16 DSGVO);
- das Recht auf Löschung der Sie betreffenden Daten nach Maßgabe des Art. 17 DSGVO. Wenn allerdings die Kodierliste bereits gelöscht ist (siehe 4.), kann Ihr Datensatz nicht mehr identifiziert und also auch nicht mehr gelöscht werden. Ihre Daten sind dann anonymisiert.
- das Recht, nach Maßgabe des Art. 18 DSGVO eine Einschränkung der Verarbeitung der Daten zu verlangen;
- das Recht auf Widerspruch gegen eine künftige Verarbeitung der Sie betreffenden Daten nach Maßgabe des Art. 21 DSGVO.

Möchten Sie eines dieser Rechte in Anspruch nehmen, dann wenden Sie sich bitte an den/die **Verantwortlichen des Forschungsvorhabens** (siehe Ansprechpartner im Briefkopf).

Verantwortlich für die Umsetzung der DSGVO ist die Universität Paderborn. Sie wird durch die Präsidentin/ den Präsidenten vertreten.
Die/den behördliche/n **Datenschutzbeauftragte/n** der Universität Paderborn erreichen Sie postalisch unter oben angegebener Adresse der/ des Verantwortlichen oder wie folgt:

E-Mail: datenschutz@uni-paderborn.de
Tel.: 05251 60-2400
http://www.uni-paderborn.de/datenschutz

Sie haben über die genannten Rechte hinaus das Recht, eine Beschwerde bei der datenschutzrechtlichen Aufsichtsbehörde einzureichen (Art. 77 DSGVO), zum Beispiel bei der/ dem für die Hochschule zuständigen

Landesbeauftragten für Datenschutz und Informationsfreiheit Nordrhein-Westfalen
Kavalleriestraße 2-4
40213 Düsseldorf
Telefon: 0211 38424-0
E-Mail: poststelle@ldi.nrw.de

6. Einwilligung In die Erhebung und Verarbeitung personenbezogener Daten

Hiermit willige ich freiwillig in die Erhebung und Verarbeitung meiner personenbezogenen Daten ein. Ich bin ausreichend informiert worden und hatte die Möglichkeit, Fragen zu stellen. Über die Folgen eines jederzeit möglichen Widerrufs der datenschutzrechtlichen Einwilligung bin ich aufgeklärt worden. Ich bin darüber informiert worden, dass durch meinen Widerruf der Einwilligung die Rechtmäßigkeit der aufgrund der Einwilligung bis zum Widerruf erfolgten Verarbeitung nicht berührt wird.
Die schriftliche Aufklärung und Einwilligung habe ich erhalten.

D| 1.2 Initial questionnaire

UNIVERSITÄT PADERBORN
Die Universität der Informationsgesellschaft

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Eingangsfragebogen

Studie: Mentale Rotation von egozentrischen Stimuli beim Stehen auf der Vibrationsplatte mit unterschiedlichen Intensitäten

Vpn-Nr.: ________	**Datum:** ___________	**Uhrzeit:** __________

Alter: _________ **Größe (cm):** ____________ **Gewicht (kg):** ____________

Geschlecht: ( ) weiblich ( ) männlich

Händigkeit: ( ) links ( ) rechts

Beruf/Studiengang: ____

Sehvermögen: ( ) uneingeschränkt ( ) eingeschränkt
( ) kurzsichtig ( ) weitsichtig
benötigte Sehhilfe/Korrektur bei der Untersuchung
( ) getragen ( ) nicht getragen
sonstige Augenerkrankungen: ___________________________________

Leiden Sie an einer neurologischen Erkrankung?
( ) ja, an folgender Erkrankung: ______________________________
( ) nein

Sportliche Tätigkeiten, die Sie regelmäßig betreiben bzw. betrieben haben:
Sportart: _____________________ von/bis (Jahr) _____________ Std./Woche: ____
Sportart: _____________________ von/bis (Jahr) _____________ Std./Woche: ____
Sportart: _____________________ von/bis (Jahr) _____________ Std./Woche: ____

Haben Sie schon einmal an einer Untersuchung zur „Mentalen Rotation“ teilgenommen?
( ) ja, an folgender Untersuchung: ____________________________
( ) nein

D| 1.3 Instruction egocentric transformation task

Instruktion

Liebe Probandin, lieber Proband,

bitte lies Dir die folgenden Informationen genau durch.

Dies ist ein REAKTIONSZEITEXPERIMENT!

Es geht also darum, so schnell wie möglich auf eine Reizdarbietung zu reagieren.

Im Folgenden wird Dir zunächst ein weißes Fixationskreuz gezeigt.

Es signalisiert Dir, dass es gleich losgeht.

Danach wird Dir ein Bild gezeigt.

Darauf ist eine Person zu erkennen, die den linken oder den rechten Arm ausgestreckt hat. Die Person wird in aufrechter Position oder in einem rotierten Winkel dargestellt.

Deine Aufgabe:

Entscheide schnellstmöglich, welchen Arm die Person ausgestreckt hat.

Antworte laut und deutlich LINKS, wenn die Person den linken Arm ausgestreckt hat.

Antworte laut und deutlich RECHTS, wenn die Person den rechten Arm ausgestreckt hat.

Beispiel für rechten Arm
richtige Antwort: **RECHTS**

Beispiel für linken Arm
richtige Antwort: **LINKS**

Deine Position:

Stehen: ohne Schuhe, enger Stand, mittig auf der Vibrationsplatte, Knie leicht gebeugt, Oberkörper aufrecht, Arme locker neben dem Körper hängen lassen

E Ethics vote

UNIVERSITÄT PADERBORN
Die Universität der Informationsgesellschaft

FAKULTÄT FÜR WIRTSCHAFTS-WISSENSCHAFTEN

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Psychology and Movement Science

- Im Hause -

15. Juli 2020

Sehr geehrte Frau Budde,

vielen Dank für Ihre Anfrage bei der Ethikkommission zu Ihrem Forschungsprojekt

„Mental Rotation in Movement-Related Settings“

vom 02.07.2020.

Im Namen der Ethikkommission der Universität Paderborn kann ich Ihnen bestätigen, dass das Projekt aus unserer Sicht ethisch unbedenklich ist und wünschen dafür viel Erfolg.

Ethik-Kommission der Universität Paderborn
Der Vorsitzende Prof. Dr. Peter F. E. Sloane

In accordance with the open science framework, the supplementary material for this dissertation can be also accessed via the following link or QR code:

https://osf.io/dp5ve/

Declaration of Authorship

I have read, understood, and accepted the current PhD regulations ("Promotionsordnung der Fakultät für Naturwissenschaften an der Universität Paderborn vom 31. März 2021").

I hereby declare that the thesis with the title 'Mental Body Rotation in Sports – Cognitive Foundations and the Influence of different Perturbations on the Performance in Mental Body Rotation Tasks with Egocentric and Object-Based Transformations' is my own work and that I have not made use of any other sources than the ones mentioned. To the best of my knowledge, I have cited all direct and indirect quotations from other sources. Additionally, I confirm that this dissertation has not been previously submitted, in whole or in part, for any degree or qualification at any university.

Paderborn, July 2024

K. Budde

Kirsten Budde