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Mental rotation and performance in basketball: effects of self-controlled and externally controlled time constraints on the processing and execution of tactic board instructions with varied orientations

Introduction

Tactical instructions in basketball and other team sports (e.g., the next offensive playing pattern) are often given in situations in which information must be processed within a limited amount of time (e.g., time-outs of 20–60 s). To deliver the instructions, coaches place themselves in front of the players and draw on tactic boards, while the players are sitting on the bench. In general, coaches have the control to determine how long players observe these instructions. It is questionable whether the observation time should be self-controlled by the players in order to optimize information processing. Moreover, coaches tend to show tactical instructions with a high spatial disparity to the players' on-court perspective. First evidence suggests that this spatial disparity is detrimental for information processing (Koopmann, Steggemann-Weinrich, Baumeister, & Krause, 2017; Schul, Memmert, Weigelt, & Jansen, 2014). However, this evidence was based on self-controlled observation time by the participants, a detail that differs from the time-out scenario in basketball matches or other settings, where procedural instructions for on-field behavior is used in sport games (e.g., physical education classes). Usually, observation time is externally controlled (by the coaches or teachers). It is therefore a matter of interest how the effects of the different mental rotation demands of the playing patterns presented on the tactic board reported by Koopmann et al. (2017) are affected by the self-control over the observation time. A systematic replication with a more detailed analysis of the disparity effect and the respective interaction with the factor of self-control (over observation time) is the aim of the current study.

Self-control and performance

In the cognitive domain, self-controlled learning, where the learner has some control over the practice situation (also called self-regulated learning), has been shown to benefit language acquisition (Ardasheva, Wang, Adesope, & Valentine, 2017) or mathematic skills (Lai & Hwang, 2016). The positive effects of self-control on different learning variables have been explained with the self-determination theory (Deci & Ryan, 2012; Ryan & Deci, 2000). Self-determination theory assumes that performance is facilitated as the self-control conditions are more adapted to the performer's needs (Deci & Ryan, 2012). Moreover, self-control influences cognitive and motivational processes (Boekaerts & Niemivirta, 2000). From the cognitive perspective, the perception of self-control should induce a more activated involvement and a deeper processing of relevant information (Sanli, Patterson, Bray, & Lee, 2013). From the motivational perspective, the self-determination theory postulates that autonomy (i.e., the experience of ownership of one's own behavior) is a basic psychological need, as it is perceived during self-controlled practice conditions and modulates motivation towards a more intrinsic quality. In turn, this may alter cognition, affect, and behavior (Katartzi & Vlachopoulos, 2011). Also other innate psychological needs such as self-efficacy/competence (i.e., the experience to produce desired outcomes and mastery), as well as relatedness (i.e., the experience to feel connected to others) should be increased in conditions of self-control, and should in turn increase intrinsic motivation (Ryan & Deci, 2000; Sanli et al., 2013; Wang, Liu, Kee, & Chian, 2019). The postulation of an increased self-efficacy/competence and the resulting increase in performance and learning is also implemented in the OPTIMAL theory of motor learning (OPTIMAL: Optimizing Performance Through Intrinsic Motivation and Attention for Learning; Wulf & Lewthwaite, 2016). The OPTIMAL theory integrates motivational (i.e., autonomy and expectancies) and attentional (i.e., focus of attention) aspects, which modulate the control processes (i.e., self-focus vs. task-related focus) and the resulting effects on acute performance and learning in motor behavior. Wulf & Lewthwaite (2016) also make an explicit prediction that self-control promotes a task-related focus through autonomy and self-efficacy. The task-related focus should in turn facilitate performance and learning. The authors of the OPTIMAL theory refer to research showing facilitating effects of self-control over multiple practice variables in the motor domain (e.g., feedback schedule [Janelle, Barba, Frehlich, Tennant, & Cauraugh, 1997; Patterson & Carter, 2010]; video instruction schedule [Wulf, Raupach, & Pfeiffer, 2005]; amount of practice [Post, Fairbrother, & Barros, 2011]; use of physical assistive devices [Chiviacowsky, Wulf, Lewthwaite, & Campos, 2012; Hartman, 2007]). Although all of the studies manipulated only one single aspect of self-control, the effects are quite large and homogeneous.

However, studies in the motor domain typically fail to show immediate facilitating effects of self-control during practice, while the superior performance of self-controlled learners occurs in delayed retention tests without the need for self-control (e.g., Bund & Wiemeyer, 2004; Janelle et al., 1997; Wulf, Clauss, Shea, & Whitacre, 2001). Bund and Wiemeyer (2004) postulate an antagonistic model for cognitive and motivational effects on performance in the context of self-controlled conditions. They assume that self-control has acute motivational benefits, as feelings of autonomy and self-efficacy might facilitate intrinsic motivation, effort, and performance. However, from the cognitive point of view, self-control demands cognitive resources for decision making processes based on the performers' knowledge of the task and individual capabilities. In the case of self-control of the observation time, the performers need to continuously evaluate the current status of their visual-spatial working memory and make decisions on whether the current representation of the instructed action sequence is accurate and stable enough to end the observation time. Thus, attentional resources are divided between the current criterion task itself and the process of self-control. In some cases, the acute beneficial effects of self-control might outweigh the detrimental effects, as some studies show immediate performance benefits of self-control during practice (Hartman, 2007; Titzer, Shea, & Romack, 1993).

Model-observer-disparity and performance

The model-observer-disparity describes the disparity between the spatial orientation of a model that needs to be imitated and the spatial orientation of the observer who intends to imitate the model's behavior (e.g., Krause & Kobow, 2013). For coaches in professional basketball (i.e., EuroLeague), it has been shown that they almost always present the visual-spatial pattern of the upcoming play from their own point of view (offensive point of view, looking to the basket) (Schul et al., 2014). In these scenarios, there is a high disparity of the players' perspective on the instruction display (midline on top and basket on the bottom of the display) and the players' actual or imagined perspective on the court (looking in the direction of the basket).

In an experimental study, Schul et al. (2014) instructed basketball experts and novices to match video clips of tactic board instructions with target stimuli showing stills with different plays. Both samples made fewer errors and needed less time when the videos and answer slides were aligned (i.e., without spatial disparity). In addition, experts were more accurate when the target stimuli were upright (basket on top in an offensive situation) than when the stimuli were presented upside down (basket on bottom). Koopmann et al. (2017) examined the effects of tactical instruction orientations in a field-oriented experimental approach in a novice sample. Participants had to view tactical instructions for one player and a sequence of three actions (route to a screen, route to catch a pass, and route to shot at the basket) under one of two different orientations. Importantly, they were free to take as much time as they needed to look at the tactic board (observation time). Afterwards, participants were asked to perform the sequence with high spatial accuracy (play execution). As the results of Koopmann et al. (2017) showed, observation times were longer and execution accuracy was lower when instructions were shown with 180°-disparity to the on-court perspective (basket on the bottom).

The results of Koopmann et al. (2017) and the results of Schul et al. (2014) were explained with the assumption that players who are instructed from the 'wrong point of view' must exploit spatial transformation processes, like mental rotation or vector inversion, in order to align the coach's instructions to their own perspective in the real game context. This alignment takes up additional cognitive resources (as reflected by increased observation times) and decreases performance accuracy (as reflected in the higher spatial errors during the execution of the playing pattern). This explanation is based on a large amount of research on mental rotation, which demonstrated higher cognitive costs for different types of stimuli whenever these need to be mentally transformed from one orientation into another (e.g., for cube figures [Shepard & Metzler, 1971; Metzler & Shepard, 1974; Parsons, 1987b], letters [Jordan, Wüstenberg, Heinze, Peters, & Jäncke, 2002; Weiss et al., 2009], faces [Cooper & Shepard, 1975; Parsons, 1987a, 1994], human body parts [Cooper & Shepard, 1975; Parsons, 1987a, 1994], and human bodies [Steggemann, Engbert, & Weigelt, 2011]).

In the context of complex motor behavior, mental rotation processes can affect motor performance crucially, as mental rotation and motor control processes show substantial interference during the planning (Olivier & De Mendoza, 2000; Wohlschläger, 2001) and execution (Wexler, Kosslyn, & Berthoz, 1998; Wohlschläger & Wohlschläger, 1998) of motor acts in behavioral studies. Congruously, neurophysiological studies reveal substantial involvement of sensory motor-related brain areas in mental rotation tasks (for a review, see

Abstract

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Abstract

Purpose. In sports games, tactical instructions are mostly presented on tactic boards under temporal constraints determined by the length of time outs (e.g., 20–60 s time outs in basketball) and coaches' instructional behavior. Thus, instructions should be presented in a way that enables fast and errorless information processing. High affordances in visual–spatial transformation (e.g., mental rotation processes) might both impede information processing and decrease execution performance. The aim of this study was to scrutinize the effect of different orientations of visual tactical displays on observation time under self-paced conditions as well as to compare the effects on execution performance to those of externally paced conditions. According to the self-determination theory, self-control over observation time is assumed to increase performance.

Methods. In a mixed-factors design with two factors, 48 participants were instructed to execute a basketball playing pattern, which was presented on a virtual tactic board in one of five different spatial disparities to the players' on-court perspective. The Self-Paced Group determined the observation time in a self-controlled manner, whereas in the Yoked Group observation times were externally controlled, i.e., the observation time was constrained to match that of the Self-Paced Group..

Results. The self-controlled time for watching the pattern before execution was significantly shorter and spatial accuracy in pattern execution was significantly higher for low disparity between instruction perspective and on-court perspective. Self-control over observation time did not affect execution accuracy.

Conclusion. The orientation effects might be explained by interfering mental rotation processes that are necessary to transform the instructional perspective into the players' egocentric perspective. According to these results, coaches should align their tactic boards to their players' on-court viewing perspective.

Keywords
Cognition · Sport games · Tactics · Instruction · Self-control

Tomasino & Gremese, 2016). Thus, execution performance of actions that are instructed with high demands on mental spatial transformation might suffer from these interferences.

Regarding the influence of movement instruction orientation on execution performance, there are some findings that can be explained by visual transformation processes, like mental rotation. Observational learning studies demonstrated facilitated imitation performance for egocentric perspectives of video- or real-models in imitation of knot-tying (Roshal, 1961), sequences of dance postures (Ishikura & Inomata, 1995), or arm movement sequences (Krause & Kobow, 2013). Krause and Kobow (2013) found orientation-dependent effects on spatial as well as temporal features of imitation performance. Ishikura and Inomata (1995) found better imitation of a sequence of seven dance poses with varied configurations of upper and lower extremities after seven repetitions of a back-view video (dancer shown from behind) than after seven repetitions of a front-view video (dancer shown from upfront). Altogether, there is substantial evidence for orientation effects of instruction displays in motor learning. The difference between the studies on movement imitation and the tactical instructions setting is that the former instruct detailed spatial configuration of the body (i.e., certain joint angles) and the latter instruct body transport in space (i.e., moving the whole body to certain locations in the environment).

The process of transferring visual information from tactic boards into on-court behavior might (in part) be similar to the observational learning studies. The task presumably relies on a complex set of subskills: spatial skills like mental rotation (i.e., rapidly and accurately rotate a two- or three-dimensional object), spatial perception (i.e., ability to determine spatial relationships with respect to the orientation of his or her own body), and spatial visualization (i.e., complicated, multi-step manipulations of spatially presented information that may also include mental rotation and spatial perception) (Linn & Petersen, 1985). All of these skills heavily rely on more general cognitive resources, like working memory capacity, in particular the visual-spatial sub-components of working memory (Kaufman, 2007). Visual-spatial working memory is involved, as intermediate representations need to be held in memory, while the object is mentally rotated. In this case, working memory is probably even more relevant after the mental rotation itself, as the rotated running paths need to be held in memory as a "cognitive map," until all running paths have been executed. This readout process is called route retracing and is one common approach to measure the quality of the internal representation (Hegarty, Montello, Richardson, Ishikawa, & Lovelace, 2006). The readout of the cognitive map, as well as the spatial orientation ability (Kozhevnikov & Hegarty, 2001), is crucial for successful behavior, when the task is to behave according to the spatial instructions (e.g., running paths). Orientation-dependent effects have been found in related tasks (e.g., virtual exploration of buildings) for the recognition of previously explored environments. Previously experienced views facilitated recognition compared to novel and mirrored views (Christou & Bülthoff, 1999; Montello, Waller, Hegarty, & Richardson, 2004). Moreover, performance in orientation surveys in virtual environments seem to depend on body orientation relative to local and global reference frames during the survey (Meilinger, Frankenstein, & Bülthoff, 2013). These findings support the assumption that representations of spatial relations in the environment are orientation-dependent.

Aim of the current study

Mental rotation research mainly focuses on parity or laterality judgment. Mental rotation effects on behavioral instructions are rarely addressed (e.g., Ishikura & Inomata, 1995; Krause & Kobow, 2013). Previous findings of the orientation effect in matching tactical instructions (Schul et al., 2014), as well as of the orientation effect on observation time and execution accuracy for tactical instructions (Koopmann et al., 2017), integrated only two levels of orientation (i.e., 0° vs. 180°) in their designs. In order to examine the function of the orientation effect, additional levels for the factor orientation should be scrutinized. In contrast to the linearity of the typical mental rotation effect (e.g., Shepard & Metzler, 1971), many experimental settings show curvilinear functions that are assumed to be caused by orientation-dependent perceptual expertise (familiarity), as discussed in studies with alphanumeric stimuli (Koriat & Norman, 1985; Experiment 1; Weiss et al., 2009), human body parts (Parsons, 1987a, 1994; Steggemann et al., 2011), or human imitation (Krause & Kobow, 2013). Besides familiarity, non-linearity might also result from different transformation processes, as mentioned earlier. Discrete processes ("sign reversal," "vector inversion") can account for non-linearity (Bock, Abeele, & Eversheim, 2003; Neely & Heath, 2010). Discrete processes might lead to better performance than gradual processes (e.g., mental rotation) in certain orientations (180° orientation). Knowledge about the function of orientation on information processing and behavior is also highly relevant, as previous research is not able to answer the question as to which degree of disparity between the tactic board orientation and the egocentric perspective significantly impedes the resulting execution performance.

Moreover, the current study addresses the impact of self-control in this setting of tactical instructions with varied orientations. This is also important from a practical perspective, as players are usually exposed to the tactical instruction with an externally controlled observation time, whereas Koopmann et al. (2017) used a self-controlled observation time, in order to test the demand for information processing, without having a control group to test the effects of this self-controlled approach. Therefore, we asked two groups of participants to view different basketball playing patterns, which were displayed on a virtual tactic board in one of five different orientations, in a first step, and then to execute these playing patterns on the court in a second step in the present study. Thereby, the Self-Paced Group was free to take as much time as needed to view the tactic instructions (i.e., different playing patterns displayed on the tactic board), whereas the observation time for the Yoked Group was constrained to match those of the Self-Paced Group. Both the effects of the control over observation time on the processing demands and play execution, as well as the effects of tactic board orientation were of interest.

The following hypotheses were derived. The first hypothesis relates to the effect of self-control over the observation time of the tactic board (i.e., when viewing the upcoming playing pattern) on execution accuracy of the on-court play: Self-control over the observation time should result in an immediate facilitation of performance during play execution, which should be reflected in better execution accuracy of the Self-Paced Group as compared to the Yoked Group (*Hypothesis 1: Effect of self-control during observation on execution accuracy*). The second and third hypotheses focus on the execution accuracy of the on-court play (self-paced and yoked group) and the effect of manipulating the tactic board orientation on the self-controlled observation time (self-paced group only): The accuracy of playing pattern execution should decrease (*Hypothesis 2: Orientation effect on execution accuracy*) and the time of observing the tactic board to study the upcoming playing pattern should increase (*Hypothesis 3: Orientation effect on observation time*) the more the spatial disparity between the player's on-court perspective and the orientation of the tactic board differ. The results will inform us about the impact of self-control over time constraints for the processing of tactic board instructions, which is not only relevant for the time-out scenario in professional basketball, but also—from a more general perspective—for supporting motor learning processes (e.g., during physical education classes).

Methods

Study design

A two-factorial design with *group* (observation time condition: self-paced vs. yoked) as a between-subject factor and *orientation* (rotation of instruction: 0°, 45°, 90°, 135°, and 180°) as a within-subject factor is used to test the hypotheses with regard to execution accuracy. As observation time can only be measured for the self-paced condition, observation time is evaluated with an ANOVA for *orientation* as a within-subject factor.

Participants

A total of 48 physically active university students enrolled in the physical education program (24 females, 24 males; mean age = 22.92 years, *SD* = 3.37) with normal or corrected-to-normal vision participated voluntarily in the experiment. As physical education students, all participants had experience in team sports occasionally, in terms of recreational sports and in their leisure time, but none of the participants had team sports experience on a higher level with constant use of tactic boards. All participants became familiar with the basketball court and experienced the use of tactic boards occasionally in physical education lessons or recreational team sport activities in advance of the experiment. Participants received course credits, but no payment. The 24 female participants as well as the 24 male participants were randomly assigned to the group with self-controlled observation time (Self-Paced Group) or the group with the yoked condition (Yoked Group). In the Yoked Group, each participant was assigned to a research twin of the Self-Paced Group and viewed the same order of plays, each with the exact same time that was chosen from the assigned research twin. Accordingly, the groups differed with respect to self-control, but were equal with respect to observation time in each trial, respectively.

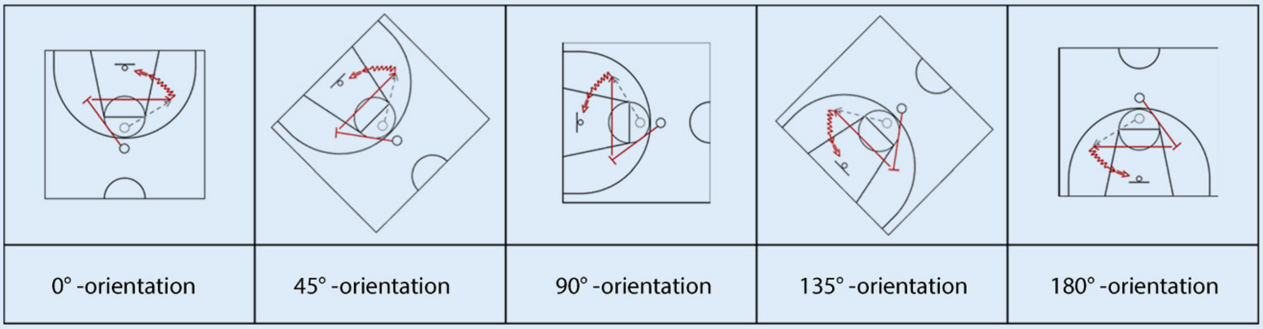

Fig. 1 ▲ Examples of instruction displays in all five orientations (paths to the three positions [screen, catch, shot] were shown in *red*)

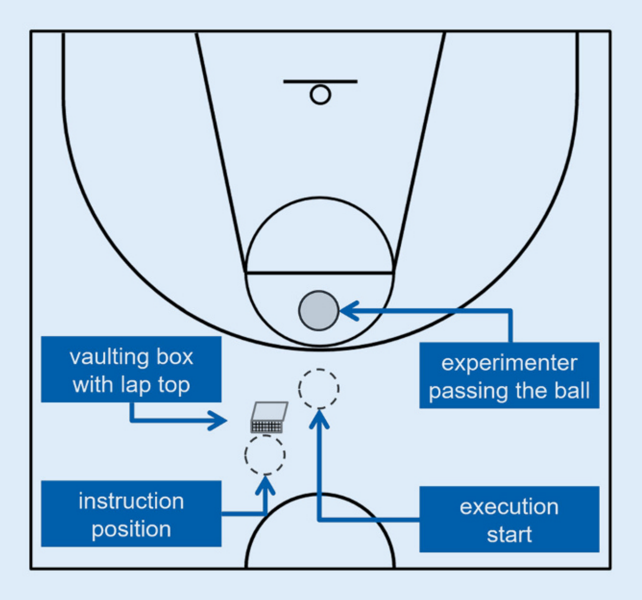

Fig. 2 ◀ Experimental setting

Stimuli

The stimulus set consisted of 10 symbolic visual tactical instructions for basketball playing patterns of one single player, displayed on a virtual tactic board on a laptop screen. These static instructions were drawn onto a schematic outline of a basketball half-court seen from above (for examples see ◘ **Fig. 1**).

In these instructional images, the starting position is marked ∼30 cm out of the three-point line, facing the basket with a white circle, which represents the participant as an offensive player. All playing patterns follow the same sequence of actions: the first route ends with setting a screen (t-arrow; a screen is a tactical means to support a teammate by blocking the opponent's way). The second route (simple arrow; solid line) ends at the spot where the participant receives the ball at the position represented by the arrow's end. The third route ends at the spot where the participant finally finishes with a layup or shot (double lined arrow). The tactical instructions also show a grey circle and a passing arrow (grey dashed arrow), which represent the experimenter's position and passing action in every playing pattern.

These 10 playing patterns were presented in five different orientations (rotated in the picture plane, clockwise or counterclockwise): 0° (basket on top), 45°, 90°, 135°, and 180° orientation (basket on bottom).

Apparatus

The study was conducted in a gymnasium on a basketball court. As shown in ◘ **Fig. 2**, the participant is facing the basket at the central position at about 30 cm to the three-point line. A laptop was placed on a vaulting box (height: 120 cm) in front of the participants near the center circle (see *instruction position*). Participants' line of gaze was directed to the basket. The experimenter remained on a marked position with a ball just inside the three-point area. The stimuli were presented with PsychoPy Software (Jonathan Peirce, Nottingham, UK; Peirce, 2007). The participants' executions were recorded with a camera (TMC-1327 GE by JAI A/S, Valby, Denmark, 1392 × 1040, 30 fps; fisheye lens: Fujinon FE185C086HA-1 by Fujifilm, Tokyo, Japan, focal length of 2.7 mm) filming the court from the ceiling of the gymnasium with a vertical optical axis (similar to a hawk's eye).

Procedure and task

The research was approved by the review board of the DGPs (German Psychological Society). All participants provided informed consent before testing, and their right to withdraw at any point was made explicit to them. The experimental sessions took about 40–60 min (dependent on self-paced observation times) for each participant. The participants were informed about the experimental procedure and about the symbols used in the instruction displays in written form. They were instructed to mark the end of the three routes with a respective action of stopping with both feet on the ground, while crossing their arms (symbol for the action of setting a screen), stretching out both arms (symbol for being prepared to receive the pass), or throwing the ball in the direction of the basket (symbol for shooting the ball). The experimenter advised the participants not to tilt the head during the observation of the tactical instructions on the screen. Each trial started at the *instruction position* with an introduction screen displaying a verbal instruction. Participants in the Self-Paced Group were instructed to memorize the playing patterns with as much time as needed to execute the playing pattern with high spatial accuracy afterwards. Participants in the Yoked Group were instructed to memorize the playing patterns within the given time period (which was matched to the schedule of the research twin in the Self-Paced Group) to execute the playing pattern with high spatial accuracy afterwards. Yoked-Group participants viewed the instruction for the whole externally controlled duration. They were not allowed to end the instruction display or to start the execution early. Please note that the Yoked–Group participants never had reliable or objective information on viewing time, as the respective research twin controlled the viewing time in each of the 50 trials. To this end, all procedures for each research twin were *ceteris paribus*, respectively. All participants received a notice that hitting the space key on the computer keyboard will initiate the following trial. After participants hit the space key, the stimulus showing a tactical instruction was displayed according to the group's condition, i.e., either until the space key was hit (Self-Paced Group) or until observation time of the yoked research twin expired (Yoked Group). There was no information on the available observation time in the Yoked Group. After the end of the observation time, participants moved to the *execution start* position marked with a yellow ground marker and executed the instructed on-court play. The experimenter passed the ball after the participants signaled their preparedness by stretching out both arms towards the experimenter. Thus, participants were not able to anticipate the catch position from the experimenter's behavior. After the execution was completed by the shot on the basket, the participant walked back to *instruction position* at the laptop. The next trial began with a start screen (to start the next instruction with a key press) 25 s after the participant hit the space key to start the execution of the previous playing pattern. These 25 s allowed for an execution without time pressure and secured an inter-trial interval of about 10–15 s and limited the tendency to hurry through the execution. All participants were instructed that time minimization for the execution of the playing pattern was not a task goal or a dependent measure. Participants were familiarized with the experimental set-up, the procedure, and the design of the instructions within the five practice trials before the actual testing phase. Participants were allowed to ask questions during the preparatory phase with five trials.

During the testing phase, the participants conducted 50 trials with 10 trials in each of the five orientations (half of them according to the clockwise or counter-clockwise rotation of 0°, 45°, 90°, 135°, and 180°) according to a pseudo-randomized order (at least two trials lay between trials with the same play).

Data analysis

Execution accuracy data: radial error

For each instruction display, the pixel coordinates of the target positions for each action (screen, catch, shot) were determined. After recording and removing the fisheye distortion (Sports Performance Analyzer, Wilhelm et al., 2010), the pictures of every action's final position were determined according to the symbolic actions. The first screenshot shows the action of setting the screen (signalized by standing still, turning point). The second screenshot shows the call for the pass (signalized by outstretched arms). The third screenshot displays the position of the shot (ball release). The pixel of the midpoint between the participants' feet was determined (Irfan View, Irfan Skiljan, Wiener Neustadt, Austria) and marked the exact position for the respective position in each trial. The rater was blinded with respect to the respective viewing condition (*orientation*) of the trials. The radial error as the distance between the target positions and the actual positions in centimeters for each 50 screens, 50 catches, and 50 shots of the participants was calculated (Microsoft Excel).

SPSS 24 (IBM, Armonk, New York, Vereinigte Staaten) was used to analyze the data with a 5 (*orientation*: 0°, 45°, 90°, 135°, 180°) × 2 (*group*: Self-Paced vs. Yoked) ANOVA with repeated measures on *orientation*. Additionally, we calculated an ANOVA for differences in plays and repetition effects. For the ANOVAs, the partial eta squared (η^2_p) was calculated as the effect size. In addition, follow up analyses were conducted with paired *t*-tests with Bonferroni-Holm procedure to account for multiple testing (Holm, 1979). For all *t*-tests Cohen's *d* for paired samples were calculated as the effect sizes. The alpha level was set to 0.05 for all statistical analyses. In the case of a violated sphericity assumption, the respective degrees of freedom were corrected according to Greenhouse-Geisser.

Processing demand data: observation time

Observation time was measured as the time between stimulus onset and stimulus offset, with both determined by hitting the space key. SPSS 24 was used to analyze the data with a one-factorial ANOVA with repeated measures on *orientation* (0°, 45°, 90°, 135°, 180°). For the ANOVA, the partial eta squared (η^2_p) was calculated as the effect size. In addition, follow-up analyses were conducted with paired *t*-tests with the Bonferroni-Holm procedure to account for multiple testing (Holm, 1979). For all *t*-tests Cohen's *d* for paired samples were calculated as the effect sizes. The alpha level was set to 0.05 for all statistical analyses. In the case of a violated sphericity assumption, the respective degrees of freedom were corrected according to Greenhouse-Geisser.

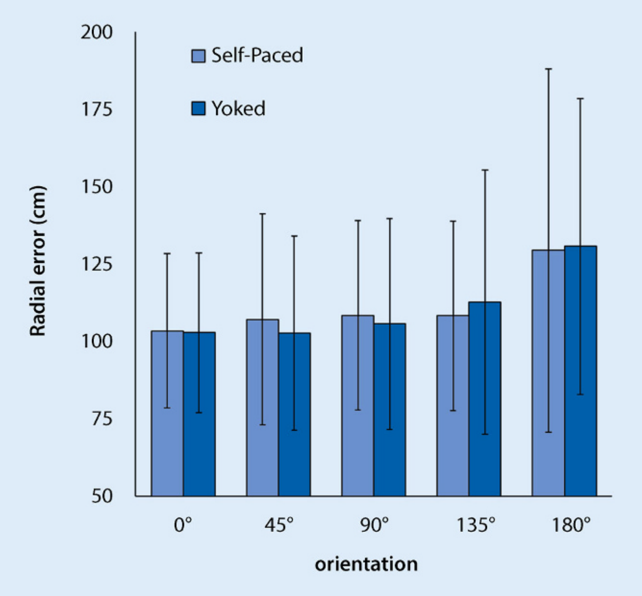

Fig. 3 ◂ Mean execution accuracy measured as the radial error in centimeters (±*SD*) for tactical instructions in all five orientations for the Self-Paced Group and the Yoked Group

Results

Execution accuracy: radial error

There is no significant main effect of *group*, $F(1,\ 46) < 0.01$, $p = 0.965$, $\eta_P^2 < 0.01$. This is not in line with *Hypothesis 1*. The interaction of *orientation* × *group* also clearly fails to be significant, $F(0.85,\ 85.12) = 0.27$, $p = 0.746$, $\eta_P^2 < 0.01$.

There is a main effect of *orientation*, $F(1.85,\ 85.12) = 10.70$, $p < 0.001$, $\eta_P^2 = 0.19$. The descriptive statistics show higher radial errors for orientations with higher degrees of rotation (see ▣ **Fig. 3**; ▣ **Table 1**). Follow-up *t*-tests reveal significant differences between 180° orientation and all other orientations (see ▣ **Table 1**). Thus, *Hypothesis 2* is supported by the data.

In addition to the calculation of the radial error, we identified error patterns that resulted from an unintentional mirror error; 2% were judged as mirrored execution patterns whenever the participants assumedly headed to the opposite side of the court (e.g., left wing instead of right wing). of these 26 mirror trials, 15 occurred after presentations with a 180° orientation.

Processing demands: observation time

There is a main effect of *orientation*, $F(2.57,\ 59.09) = 21.81$, $p < 0.001$, $\eta_P^2 = 0.49$ (see ▣ **Fig. 4**). Post-hoc single comparisons show that there are significant differences for all single comparisons except 0° vs. 45° and 90° vs. 135° (see ▣ **Table 1**). Hypotheses 4 is supported.

Analysis of speed-accuracy trade-offs

To analyze potential speed-accuracy trade-offs on group level (Self-Paced Group), we calculated correlations of the observation time and radial error for 0°-orientation stimuli ($r_{\mathrm{Pearson}} = -0.059$; $p = 0.784$), 45°-orientation stimuli ($r_{\mathrm{Pearson}} = -0.074$; $p = 0.731$), 90°-orientation stimuli ($r_{\mathrm{Pearson}} = -0.112$; $p = 0.602$), 135°-orientation stimuli ($r_{\mathrm{Pearson}} = 0.130$; $p = 0.544$), and the 180°-orientation stimuli ($r_{\mathrm{Pearson}} = 0.206$; $p = 0.334$), all being non-significant.

Difficulty of play and repetition effects

We analyzed the difficulty of the 10 plays as well as repetition effects with a 5 (*repetition*) × 10 (*play*) × 2 (*group*) ANOVA and found a significant effect for *repetition*, $F(1.87,\ 85.96) = 22.10$; $p < 0.001$; $\eta^2p = 0.32$, but no *repetition* × *group* interaction, $F(1.87,\ 85.96) = 0.27$; $p = 0.752$; $\eta^2p < 0.01$. Follow-up tests revealed that the second repetition has a higher error than the first trial of a respective play, $t(4) = 2.68$, $p = 0.030$, $d = 0.39$, and that the error decreases from repetition 2–3, $t(4) = -5.60$, $p < 0.001$, $d = -0.81$, 3–4, $t(4) = -3.15$, $p = 0.012$, $d = -0.45$, and 4–5, $t(4) = -2.27$, $p = 0.028$, $d = -0.33$.

Likewise, we found a main effect for play, $F(5.34,\ 245.92) = 9.17$; $p < 0.001$; $\eta^2_P = 0.17$, but no *repetition* × *group* interaction, $F(5.34,\ 245.92) = 1.12$; $p = 0.336$; $\eta^2_P = 0.02$. Follow-up tests revealed several significant single-comparisons showing that play 1, 2, 3, 4, and 6 have lower radial errors than many of the other plays and play 5 and 10 have higher errors than many of the other plays, $ps \leq 0.032$, $ds \geq 0.52$ (see ▣ **Table 2**).

Discussion

Hypotheses-related discussion

The effect of self-control on execution accuracy

We assumed that the overall performance and the influence of orientation is moderated by self-control over viewing duration (Hypothesis 1). All effect sizes with the factor *group* (Self-Paced vs. Yoked) were small (all $\eta_P^2 < 0.01$). This was also the case when single plays with varied difficulty and the single repetitions of plays effects were analyzed. According to the self-determination theory (Deci & Ryan, 2012), as well as the OPTIMAL theory of motor learning (Wulf & Lewthwaite, 2016), the self-controlled conditions should have facilitated performance, as these conditions are more adapted to the performers' needs and the performers' intrinsic motivation is increased. The perception of self-control is assumed to induce a more active involvement and a deeper processing of relevant information (Sanli et al., 2013). The antagonistic model of Bund and Wiemeyer (2004) also relates to these ideas and postulates additional cognitive costs, while the performer is involved in a self-controlled process, i.e., the self-

Table 1 Statistics for the follow-up single comparisons for the radial error with adjusted *p*-values according to Bonferroni-Holm

Single comparison	Radial error			Observation time		
	T	*p*	*d*	*t*	*P*	*d*
0° vs. 45°	0.60	0.181	0.09	0.77	0.444	0.16
0° vs. 90°	1.56	0.200	0.23	7.65	0.007*	0.72
0° vs. 135°	2.23	0.055	0.32	1.55	<0.001*	0.95
0° vs. 180°	4.43	<0.001*	0.64	3.18	<0.001*	1.56
45° vs. 90°	0.66	0.325	0.10	3.91	0.004*	0.80
45° vs. 135°	1.64	0.158	0.24	4.03	0.003*	0.82
45° vs. 180°	3.55	0.001*	0.51	4.40	<0.001*	1.29
90° vs. 135°	1.46	0.190	0.21	0.353	0.268	0.32
90 vs. 180°	3.75	0.001*	0.54	6.34	0.001*	0.90
135° vs. 180°	3.04	0.004*	0.44	4.63	0.013*	0.65

*Significant single comparison ($p < 0.05$)

Table 2 Mean radial errors for the 5 repetitions of the 10 plays

	Play										
Repetition	1	2	3	4	5	6	7	8	9	10	Mean
1	131.2	110.0	107.1	96.2	126.1	118.4	117.3	113.1	114.4	148.9	118.3
2	114.7	101.1	104.1	112.3	151.5	107.6	134.9	124.4	125.2	169.6	124.5^{a}
3	92.6	100.7	91.7	98.5	137.8	98.7	115.8	111.1	108.6	123.7	107.9^{a}
4	86.4	102.5	81.8	90.3	132.3	93.4	108.7	113.1	99.9	112.9	102.1^{a}
5	86.8	97.7	75.0	87.6	125.8	87.9	99.6	108.9	105.1	107.3	98.2^{a}
Mean	102.4 $*_{5}$	102.4 $*_{5}$	91.9 $*_{5,7–10}$	97.0 $*_{5,10}$	134.7 $*_{1–4,6,7,9}$	101.2 $*_{5,10}$	115.3 $*_{3,5,10}$	114.1 $*_{3}$	110.6 $*_{3,5}$	132.5 $*_{3,4,6}$	–

*Significant differences ($p < 0.05$) to other plays

^{a}Significant difference ($p < 0.05$) to repetion $n - 1$

control process itself demands for cognitive resources. In the case of self-control of the observation time, performers continuously need to evaluate the current status of their visual-spatial working memory and make decisions as to whether the current representation of the instructed action sequence is accurate and stable enough to end the observation time. Thus, attentional resources are divided between the current criterion task itself and the process of self-control. In the case of a cognitive demanding task, like the tactical instruction task used here, the beneficial effects of self-control might not outweigh the immediate detrimental effects of self-control during practice. We expect that any potential antagonistic effects of self-control should be operant during the observation phase, as the self-control demand ends after the decision to end the instruction display. However, it cannot fully be decided whether these effects are only based on the mental rotation itself or any other relevant cognitive process, such as spatial perception and spatial visualization.

The effect of orientation on execution accuracy and observation time

According to Koopmann et al. (2017), we replicated the basic finding that the orientation of visual tactical instructions for basketball playing patterns affects the execution accuracy (radial error; *Hypothesis 2*) and processing demands (self-controlled observation time; *Hypothesis 3*) when participants are instructed to view the visual instructions and transfer them into actions on the court. As hypothesized, accuracy decreased and observation time increased with an increase in the disparity between the perspective of the instruction and the players' perspective, while they executed the playing pattern on the basketball court or while memorizing the execution pattern during the instruction. The large effect size for observation time (current study: $d = 1.56$; Koopmann et al., 2017: $d = 1.71$) was relatively comparable for the respective comparison of 0° vs. 180° orientation with self-chosen observation times. As in the previous study, we found more 180° trials with a mirrored execution as compared to other orientations with lower disparity, which is also well in accordance with our *Hypothesis 2*.

It can be assumed that the players utilize mental rotation processes in order to transform the instructional perspective into the on-court perspective. The demands for information processing and performance errors are known to increase with the affordance for mental rotation (e.g., Shepard & Metzler, 1971). This has also been shown to affect the mental rotation of tactic boards in basketball (Schul et al., 2014), and the higher processing demands for mental rotation may well explain the present pattern of results.

Basically, the effect of instruction orientation on execution accuracy (radial error) is also replicated, but with a much

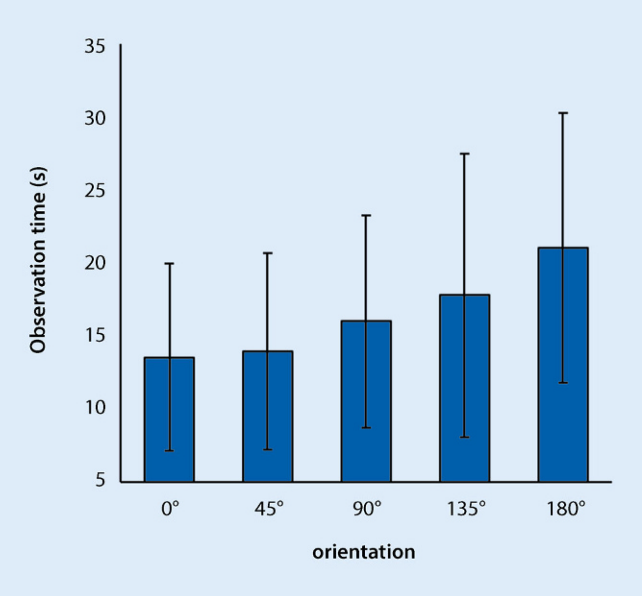

Fig. 4 ◀ Mean observation time in seconds (±*SD*) for tactical instructions in all five orientations for the Self-Paced Group

smaller effect size for the 0–180° comparison, in contrast to the previous study. The Self-Paced Group alone (comparable condition to previous study) shows a medium effect size ($d = 0.57$), which substantially fails to replicate the effect size of Koopmann et al. (2017) ($d = 1.80$; calculated from η_p^2). One might argue that participants have differentially prioritized to execute accurately at the cost of longer viewing durations in the present study, but this trade-off should also affect the effect size for the observation time, which is relatively comparable. At this point in time, this small inconsistency between the present results and the results of Koopmann et al. (2017) is difficult to interpret.

Going one step further, we also analyzed the linearity of the orientation effect and found increasing observation times over the five orientations. From a practical perspective, the number of players in a basketball team complicates the realization of a comparable alignment for the whole team during tactical instructions. Knowledge about the underlying function between viewing angle, processing time, and execution performance is valuable. Regarding our data, it seems as if low increases in disparity from an 0° viewing angle (up to around 45°) do not harm information processing ($d = 0.16$ for 0° vs. 45° orientation) or the resulting performance ($d = 0.09$ for 0° vs. 45° orientation; $d = 0.23$ for 0° vs. 90° orientation; $d = 0.32$ for 0° vs. 135° orientation) considerably, as indicated by the small effect sizes. Higher increases in disparity significantly affect information processing with large effect sizes, as reflected in longer observation times. The resulting execution accuracy seems to be more robust, but is also substantially harmed by higher increases in disparity with medium effect sizes (e.g., $d = 0.64$ for 0° vs. 180° orientation). The observation time curve fits equally to a linear ($R^2 = 0.104$) and a quadratic regression ($R^2 = 0.110$), whereas the radial error fits slightly more to a quadratic ($R^2 = 0.063$) than a linear regression ($R^2 = 0.049$).

Lower effects for moderate orientation disparities are often present when there is a supposedly orientation-dependent perceptual expertise (Koriat & Norman, 1985; Krause & Kobow, 2013). This might result from experience with similar everyday tasks, like navigating with geographical maps on paper or digital devices (e.g., "you are here maps," during hiking, city tours, visiting museums or shopping centers; Montello, 2010). Nonlinearity might also result from differently engaged transformation processes (continuous and discrete processes; Bock et al., 2003). According to this view, the 180° transformation might not be accomplished via a gradual mental rotation, but by inverting the axes of the internal reference frame. These mechanisms might explain nonlinear functions in orientation-dependent task performance (e.g., Bock et al., 2003; Neely & Heath, 2010). Deriving the underlying mechanisms from the behavioral data is vague, but the orientation-dependent perceptual expertise approach seems to be more suitable, as an explanation as vector inversion would lead to rather low performance decrements in 180° conditions, which is obviously not the case in the current data set. Scrutinizing neural correlates of mental rotation tasks might help to add knowledge on the underlying mechanisms in this specific setting (Jordan et al., 2002; Provost, Johnson, Karayanidis, Brown, & Heathcote, 2013).

In addition to the orientation dependent effects on radial error, we found more mirrored executions of trials where participants ran to the wrong side of the court (e.g., left instead of right) in the 180° orientation ($n = 15$) as compared to the 0° orientation ($n = 3$), 45° ($n = 0$) or the 90° and 135° orientation (both $n = 4$). These mirror errors were comparatively seldom (about 2% of the trials), but are most relevant from a practical perspective. While small deviations from the instructed running paths might be compensated, running to the wrong side of the court might totally disrupt the planned playing pattern.

Summing up, this study shows costs of mental rotation for tactical instructions in a sports scenario (see also Schul et al., 2014 as well as Koopmann et al., 2017). Therefore, high affordances of mental rotation should be avoided to maximize effectiveness of instructions in movement-related scenarios, like sports games. Small disparities (around 45°) from ideal observation angles seem to be compensated; medium disparities (around 90–135°) are also compensated with respect to the resulting performance, but accompanied by a significantly higher information processing demand; and large disparities (around 180°) lead to an increased processing demand as well as significant performance decrements. The current design disentangled the effects of temporal constraints by using a yoked design in which the presence of a time limit was present without being confounded with the observation duration. This time limit did not affect the accuracy performance compared to a condition of self-paced observation time.

Limitations and research desiderata

The Yoked Group was not informed about the observation time available. Making predictions about the effect of the availability of this information is difficult, but additional information on observation time might facilitate strategic decisions, like the decision on how much time can be spent on each of the single routes. Therefore, varying the availability of knowledge about the observation time with an analysis of eye gaze behavior would be an interesting research desideratum. With respect to external validity, externally controlled observation time corresponds to professional practice, where coaches determine the observation time.

So far, the orientation effects on performance (execution accuracy) might be confounded by observation time, as orientations with higher disparities were viewed with longer durations. Therefore, the effects of temporal constraints might be further scrutinized by setting a fixed observation time for all orientation levels (e.g., the mean observation time for all orientation levels in the current experiment). With respect to self-controlled conditions, long-term learning effects should be scrutinized in future studies, as they might differ from the immediate effects (Bund & Wiemeyer, 2004). Externally or self-controlled time limits are only one of several real-world challenges that should be examined (e.g., performance pressure, complexity, preserving focused attention besides distraction, players' position during instruction; see Koopmann et al., 2017). Besides the player centered discussion, the coaches' perspective should not be neglected in future studies (see Koopmann et al., 2017).

Direct practical implications of the current findings are limited to procedural instructions for on-field behavior of novices in sport games (e.g., physical education classes and other settings with competitive beginners). At the same time, the impact of self-control over a particular practice variable has been of considerable interest in the field of motor learning (e.g., Bund & Wiemeyer, 2004; Hartman, 2007; Titzer et al., 1993). These studies demonstrated that placing the learner in some form of self-control during practice can be an effective tool to enhance motor learning and performance. In the present study, however, self-control did not affect participants' performance, when testing a sample of novices in basketball. Thus, future research should investigate whether the effect of self-control occurs in an expert sample, as one could argue that expert athletes might be less demanded by the processing of the tactical instruction displays and, therefore, might be less prone to cognitive overload by the simultaneous cognitive demands of self-control processes (i.e., evaluation and decision making). Thus, in the expert sample, beneficial effects of self-control might outweigh the antagonistic (detrimental) acute effects of self-control.

Different samples should be examined in the future, as a number of individual factors, such as expertise and gender, might affect the results. Although the results of Schul et al. (2014) do not suggest the assumption that extensive experience with upside-down tactical instructions eliminates the orientation effects, there are substantial expertise effects in mental rotation research (Voyer & Jansen, 2017). Different populations with frequent affordances of mental rotation (e.g., computer games: Cherney, 2008; De Lisi & Wolford, 2002; computer aided design: Onyancha, Derov, & Kinsey, 2009) show transfer effects on laboratory mental rotation tasks. In the motor domain, several studies found that motor expertise is a predictor for mental rotation performance (e.g., divers: Feng, Li, Ji, & Zhang, 2017; gymnasts: Heinen, Jeraj, Vinken, & Valentzas, 2012; Jansen & Lehmann, 2013; Steggemann et al., 2011). Therefore, the effect size of the mental rotation effects for experts in this setting should be examined to further judge their practical relevance. In addition, gender differences should be scrutinized, as these effects are evident in mental rotation performance in other settings (e.g., Jansen & Heil, 2009; Peters et al., 1995). In the case of yoked-group designs, research twins should be matched according to gender. Moreover, the specific expertise related to the use of tactic boards, as well as the general mental rotation ability and other spatial abilities, should be tested in order to foreclose their confounding influence on the results.

The current study has implications for the use of tactical instructions in game situations like time-outs where short-term recall is afforded. As tactical instructions are also used in practice sessions with the aim of teaching playing patterns, the long-term effects of the use of different instruction orientations might be scrutinized. Low mental rotation affordances clearly seem to help short-term recall, but often learning under more difficult conditions facilitates long-term retention effects (e.g., Guadagnoli & Lee, 2004). For example, switching tasks in a random or serial order (high contextual interference) leads to inferior practice performance compared to blocked practice conditions (low contextual interference), but with regard to long-term retention the higher contextual interference practice conditions often have facilitative effects (Brady, 2004, 2008; Shea & Morgan, 1979). So perhaps long-term learning of tactical playing patterns might also benefit from switching tactical instructions' perspective in practice, as this might be a way to increase the difficulty of practice to a more effective level especially for learners with a higher level of expertise.

Conclusion

The findings of this study impact instructional strategies in sport games. Self-control over observation time does not seem to alter acute transfer of information to execution of tactical instructions. Reinforcing the conclusions drawn by Schul et al. (2014) and the findings of Koopmann et al. (2017), the processing and execution of playing patterns is negatively affected by an increase in disparity between the instruction orientation and the players' on-court perspective, while there is a given range of low disparity orientations without notable performance decrements. Reducing players' time for information processing by a significant amount leaves coaches and players more time to repeat or emphasize further tactical instructions during short time-outs.

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Compliance with ethical guidelines

Conflict of interest. D. Krause and M. Weigelt declare that they have no competing interests.

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