Journal of Sports Sciences
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/rjsp20

Motor adaptation in complex sports - The influence of visual context information on the adaptation of the three-point shot to altered task demands in expert basketball players

Tino Stöckel [a] & Udo Fries [b]

[a] Department of Sport Science, Sport & Exercise Psychology Unit, University of Rostock, Ulmenstraße 69, Rostock, 18057, Germany

[b] Leipzig University, Faculty of Sport Science, Institute of General Kinesiology and Athletes Training, Jahnallee 59, Leipzig, 04109, Germany

Version of record first published: 10 Dec 2012.

To cite this article: Tino Stöckel & Udo Fries (2013): Motor adaptation in complex sports - The influence of visual context information on the adaptation of the three-point shot to altered task demands in expert basketball players, Journal of Sports Sciences, 31:7, 750-758

To link to this article: http://dx.doi.org/10.1080/02640414.2012.750003

Journal of Sports Sciences, 2013
Vol. 31, No. 7, 750–758, http://dx.doi.org/10.1080/02640414.2012.750003

Motor adaptation in complex sports – The influence of visual context information on the adaptation of the three-point shot to altered task demands in expert basketball players

TINO STÖCKEL[1] & UDO FRIES[2]

[1]*University of Rostock, Department of Sport Science, Sport & Exercise Psychology Unit, Ulmenstraße 69, 18057 Rostock, Germany, and* [2]*Leipzig University, Faculty of Sport Science, Institute of General Kinesiology and Athletes Training, Jahnallee 59, 04109 Leipzig, Germany*

(Accepted 12 November 2012)

Abstract

We examined the influence of visual context information on skilled motor behaviour and motor adaptation in basketball. The rules of basketball in Europe have recently changed, such that that the distance for three-point shots increased from 6.25 m to 6.75 m. As such, we tested the extent to which basketball experts can adapt to the longer distance when a) only the unfamiliar, new three-point line was provided as floor markings (NL group), or b) the familiar, old three-point line was provided in addition to the new floor markings (OL group). In the present study 20 expert basketball players performed 40 three-point shots from 6.25 m and 40 shots from 6.75 m. We assessed the percentage of hits and analysed the landing position of the ball. Results showed better adaptation of throwing performance to the longer distance when the old three-point line was provided as a visual landmark, compared to when only the new three-point line was provided. We hypothesise that the three-point line delivered relevant information needed to successfully adapt to the greater distance in the OL group, whereas it disturbed performance and ability to adapt in the NL group. The importance of visual landmarks on motor adaptation in basketball throwing is discussed relative to the influence of other information sources (i.e. angle of elevation relative to the basket) and sport practice.

Keywords: *goal-directed behaviour, expert performance, distance estimation, visuo-spatial landmarks, conditioned motor response*

Introduction

A key capability of the human motor system is to immediately perceive changes in the environment, and to rapidly adapt to these changes by updating the internal representation of the movement. The motor system utilises sensory feedback information in order to balance the respective movement parameters relative to environmental changes in order to maintain functionality under various conditions. Evidence of the motor system's ability to rapidly adapt to altered conditions during goal-directed behaviour comes from experiments on prism adaptation (e.g., Fernandez-Ruiz & Diaz, 1999; Ooi, Wu, & He, 2001; Redding & Wallace, 1993) and force field adaptation (e.g., Krakauer, Ghilardi, & Ghez, 1999; Lackner & DiZio, 1994; Sarlegna, Malfait, Bringoux, Bourdin, & Vercher, 2010; Shadmehr & Mussa-Ivaldi, 1994), and can also be derived from studies in which participants reach for targets of varying distance (e.g., Vickers, 1996, 2009; Williams, Singer, & Frehlich, 2002). The majority of these studies involved laboratory tasks. However, the extent to which motor adaptation is present in a real-life setting is relatively unknown. With this in mind, the aim of the present study was to examine whether motor adaptation is observable in a complex sporting context.

The rationale and motivation for conducting this study was a recent change in the European basketball rules. Prior to the 2010/2011 season the distance for three-point shots was 6.25 m from the basketball rim. However, with the beginning of the 2010/2011 season, players had to shoot the ball from 6.75 m in order for the shot to count as three points. In addition, the lines on the court were updated to reflect the change in distance. This rule change provided the opportunity to investigate motor skill

Correspondence: Tino Stöckel, University of Rostock, Department of Sport Science, Sport & Exercise Psychology Unit, Ulmenstraße 69, 18057 Rostock, Germany. E-mail: tino.stoeckel@uni-rostock.de

adaptation in expert performers in a real-life setting and to report to coaches and athletes in sports how to deal with such changes in daily practice. Therefore, the study was conducted immediately prior to the 2010/2011 season and hence before the rule change.

The theory of generalised motor programmes (GMP-theory) postulates that the ability of the motor system to rapidly adapt to changes is linked to generality effects in the control of skilled motor behaviour. That is, increasing experience not only improves performance in the practised task, but also improves performance of all skills that belong to the same class of actions (e.g. the class of set-shots in basketball) by updating the schema-rules (Schmidt, 1975, 2003). Thereby, perceptual input of a specific situation (recognition of the schema) calls for the retrieval of a movement representation (including a set of motor commands) that describes the invariant parameters of the respective class of action. By evaluating the actual task demands (e.g. the longer distance of the three-point line to the basketball rim) these motor commands are updated to meet the specific demands of each skill within that class of actions – allowing for motor skill generality with increasing experience. In general, the evaluation of actual task demands consists of evaluating the different sources of perceptual information. The demands of throwing in basketball are estimated by using direct visual online information until ball release (cf. Oudejans, van de Langenberg, & Hutter, 2002) from the location of the rim in relation to one's own position (e.g. de Oliveira, Oudejans, & Beek, 2009; Keetch, Schmidt, Lee, & Young, 2005). Keetch et al. (2005, p. 974) postulated that this information is the "primary (and perhaps sole) source of perceptual input" that is used when preparing for the free-throw movement as one shot in basketball from a specified line on the court. In their opinion, floor markings are an incidental cue that plays only a secondary role in skilled free-throw performance, because throwing performance did not differ between conditions where the floor markings were present or absent (Keetch et al., 2005, Exp. 2).

However, in expert performers the appropriate evaluation of perceptual input not only depends on the veridical perception of the task demands, but on the constancy of learned properties of the environmental context, which could serve as invariant parameters for the control of the respective action. The deliberate practice approach (see Ericsson, Krampe, & Tesch-Römer, 1993; Ericsson & Lehmann, 1996) holds that extensive amounts (i.e. more than 10 years and/or 10,000 hours) of domain-specific practice leads to specific adaptations in perceptual-motor skills characterised by maximum adaptations to task constraints. This has been evidenced in a number of tasks from various fields of application, such as music, typing, chess, and sports (see Ericsson & Lehmann, 1996). Thus, it is very likely that expert performance and the ability to rapidly adapt skilled behaviour to changed conditions are inhibited by altered task constraints, such as the larger distance for three-point shots and the new floor markings in European basketball.

De Oliveira et al. (2009) demonstrated that jump-shot performance in basketball experts decreased when the height of the rim was altered. Similarly, Breslin, Hodges, Kennedy, Hanlon, and Williams (2011) showed that free-throw performance decreased in expert basketball players when the weight of the ball was altered. Both studies suggest a significant role of task-related context information for throwing performance in basketball and highlight that stable context information can become part of the movement representation (and will not be subject to evaluation of task demands) with extensive amounts of practice. It is highly probable that a readily available behavioural signature of motoric-spatial coding (Chieffi & Allport, 1997) relative to constant perceptual cues exists, which serves to hasten the retrieval of an appropriate motor response due to massive amounts of practice. Accordingly, it remains to be seen whether expert performance is influenced by constant perceptual cues, and whether or not expert performers are able to rapidly adapt their domain-specific skilled behaviour to altered task constraints, like the larger distance and the new floor markings in basketball.

Thus, the aim of the present study was to examine the extent to which stable environmental visuo-spatial cues influence (either in a facilitatory or inhibitory manner) the adaptation of skilled motor behaviour to altered task constraints. More specifically, we sought to determine whether distance control in skilled far-aiming movements is calibrated relative to task-related visuo-spatial landmarks, or based on visual estimation of the actual distance to the target. For this purpose, we had 20 expert basketball players take jump shots from the standard three-point distance (6.25 m) followed by jump shots from a 50 cm greater distance (6.75 m). The shots from 6.25 m were taken on a basketball court as was standard until the 2009/2010 season with the three-point line marker at 6.25 m, whereas the shots from 6.75 m were either taken on a court where the greater distance was marked on the floor in addition to the old three-point line (OL group), or a court with only the new three-point line marker at the greater distance (NL group).

We assessed the percentage of hits for all shots and additionally analysed the landing position of the ball (i.e., throwing tendencies) for half of the shots (i.e. the first and last block from each distance). Since the experts in the present experiment had practised the three-point shot for more than 10 years at a constant and reliably marked distance of 6.25 m, we hypothesised that the information provided by the floor marking would be necessary to successfully perform the three-point shot. Thus, the three-point shot should be constrained by this line and its constant properties (including the distance of 6.25 m), as has been shown for the height of the basket (e.g., de Oliveira et al., 2009; Fitzpatrick, Pasnak, & Tyer, 1982). If this were the case, the group that performed on the court with the new lines, in addition to the familiar floor markings, should be able to better adapt to the larger distance. Thus, the OL group's percentage of hits and consistency in throwing tendencies should be higher compared to those of the group which performed the 6.75 m three-point shots on the court with only the new lines (NL group). In contrast, both groups should perform equally from both distances if three-point shooting performance is not influenced by ground surface information, and direct visual estimation of the actual distance to the basket is sufficient for distance control in expert performers, as is assumed by others (e.g., de Oliveira et al., 2009; Keetch et al., 2005).

Methods

Participants

Twenty expert male basketball players (mean age = 24.3 years, $s = 3.0$ years) volunteered to take part in the present study. All were players of the second or third highest-ranking basketball leagues in Germany, had at least 10 years of coached practice in a basketball club (on average 12.9 years of coached practice, $s = 3.1$; cf. definition of an expert performer, Ericsson & Lehmann, 1996; Vickers, 1996) and at least 5 years of experience playing on the German regional level (third league). Participants were deemed to be right-handed, the best three-point shooters on their respective teams and playing on the guard and forward position. The experiment was conducted before the rule change, so participants did not have experience on courts with the new floor markings and the distance increase for three-point shots. Informed consent was obtained prior to participation in the experiment. The experiment was approved by the institutional review board, and conformed to the declaration of Helsinki.

Experimental set-up and design

All participants performed three-point shots under two distance conditions: 40 shots from 6.25 m (the old three-point distance in European basketball) followed by another 40 shots from 6.75 m (the new three-point distance in European basketball). Participants were not explicitly informed about the different distances. The experiment was run on three comparable half-courts with standard backboards and rims on all courts. Courts only differed in terms of the ground surface information and placement of the three-point line. Both groups started with 40 shots from Court 1 with the three-point line at 6.25 m as was standard until the 2009/2010 season in European basketball (see Figure 1a). Then, the new lines (NL) group continued with another 40 shots on Court 2 with the three-point line at 6.75 m, in accordance with the change of rules before the beginning of the 2010/2011 season in European basketball (see Figure 1b). In contrast, the old lines (OL) group performed their second 40 shots on Court 3 with the new distance marked in addition to the old lines at three shooting spots (see Figure 1c). The order of shots was the same for all participants. All participants first shot from 6.25 m with the familiar floor markings, followed by shots from the larger distance with either familiar (OL) or unfamiliar (NL) floor markings. Masking tape (5 × 2 cm) was used to mark the three shooting positions for three-point shots on each court. Position 1 was straight in front of the basket. Positions 2 and 3 were the right and left wing positions on the virtually extended free-throw line (see Figure 1). Participants were required to take 20 shots from Position 1 and 20 shots from the wing positions in a predefined order. Participants were randomly assigned to the OL and NL groups prior to the experiment without being aware of these differences, and each participant was tested alone. Shots were performed with an official FIBA (Fédération Internationale de Basketball) basketball (size 7, Molton). Throwing performance was assessed by an expert rater (i.e., an active basketball player) sitting at a predefined position on the (right) side-line of the court (see Figure 1a). Five athletes were coded by two scorers independently, whose ratings had correlation coefficients of 0.94 (throwing tendencies) and 1 (percentage of hits). Therefore, the remaining athletes were coded by only one scorer.

Procedure

Upon entering the gym, the task was explained to the participants, and after all questions were answered, they completed the informed consent and personal data forms. Participants were instructed to perform the three-point shot to their best ability in every single trial. For warm-up, each player was required to take 25 shots from five predefined positions within the three-point field goal area. No three-point shots were taken during warm-up. Then, each participant ran through four blocks of 10 three-point shots from three different positions in a predefined order.

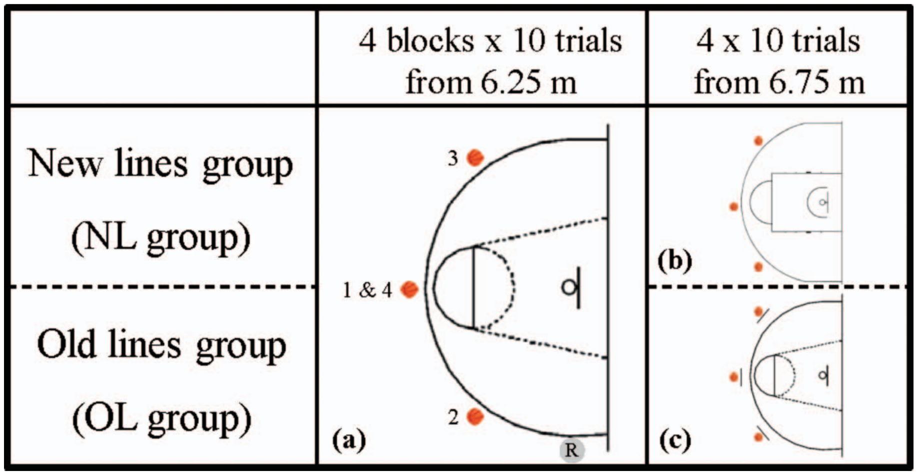

Figure 1. Experimental setup and design. The figure displays the respective courts on which participants performed the three-point shooting in accordance with their group affiliation. (a) Court 1 with the three-point line at 6.25 m, as was standard until the 2009/2010 season in European basketball. (b) Court 2 with the three-point line at 6.75 m, as is now standard as of the beginning of the 2010/2011 season in European basketball. (c) Court 3 with the new distance marked in addition to the old lines at three shooting spots. Shooting spots and the order of blocks are indicated by the balls and the respective block number beneath. The *R* in Figure 1a indicates the position of the rater on each of the three courts.

Participants started with 10 shots from Position 1, followed by 10 shots from Position 2 (block 2), 10 shots from Position 3 (block 3), and another 10 shots from Position 1 in block 4 (see Figure 1a). Rest between blocks was limited to the time needed to change to the next position. In order to ensure enough time to prepare each shot, participants were allowed to initiate each shot at their own pace. After each shot, an assistant immediately returned the ball to the participant for the next shot. After four blocks of testing, there was a standard rest period of 15 minutes including the change to Court 2 or 3 (depending on participant's group affiliation). On the new court, each player was required to take another 25 warm-up shots (equal to the first series of warm-up shots) to physically prepare after the rest and to make themselves familiar with the court before completing another 40 shots from 6.75 m. The procedure for the second forty shots was the same as for the shots from 6.25 m. The total duration of the testing session was approximately 60 minutes.

Data and statistical analysis

Each shot was registered as 'hit' or 'miss' according to official basketball rules (i.e., ball goes through the rim or not). Additionally, throwing tendencies as a measure of distance error were assessed for each shot from Position 1 (i.e., in blocks 1 and 4) on a 5-point scale ranging from -2 to 2, with -2 indicating that a shot was too short without hitting the rim, -1 for undershooting the basket and hitting the rim, 0 if the ball went through the rim without hitting the rim or the backboard, 1 for overshooting the basket and hitting the rim, and 2 for overshooting the basket and hitting the backboard. Notably, these scores were given independently from whether a shot was a hit or a miss; in fact, all scores besides -2 (miss) and 0 (hit) could have been a hit or a miss. Throwing tendencies for Positions 2 and 3 were not recorded, because of the distorted perspective of the rater relative to the player-rim-line, which could have biased the results.

The percentage of hits, as the variable measure with the highest ecological validity, was arcsine transformed (by taking the arcsine of the square root of the proportional data) and submitted to a group (NL group, OL group) × distance (6.25 m, 6.75 m) × block (1 ~ 4) analysis of variance (ANOVA), with repeated measures on the last two factors. The factor *group* was between-participants in order to test for differences in success rates between groups and distances. Even though we have done the statistical test on the transformed variable, we report and display the back-transformed results for better illustration of the data. Another group (NL group, OL group) × distance (6.25 m, 6.75 m) × block (1 ~ 4) ANOVA with repeated measures on the last two factors and *group* as a between-participant factor was performed for throwing tendencies (averaged across all trials of one block), to test more specifically the direction of the error from the target, and the potential differences between groups and distances. Additionally, throwing tendencies for shots from 6.75 m were compared between groups on a trial-by-trial basis to test for adaptation effects using a group (NL group, OL group) × trial (1 ~ 20) ANOVA with repeated measures. Notably, only shots taken from Position 1 (i.e., block 1 and 4) at 6.75 m have been included. Bonferroni corrections were made to adjust the alpha level for conducting two ANOVAs (i.e., alpha = 0.05/2 = 0.025). For any significant main or interaction effects, post hoc pairwise comparisons using the Sidak adjustment were performed between any two given conditions.

Results

Percentage of hits

Analysis indicated that the percentages of hits (displayed in Figure 2) differed significantly between both distances, $F(1,18) = 8.24$, $P < 0.01$, $\eta^2 = 0.31$, with a higher percentage of hits from 6.25 m (M = 52.0%, s = 4.1%) compared to 6.75 m (M = 40.6%, s = 6.3%). This effect was mainly driven by a significant interaction between group and distance, $F(1,18) = 6.05$, $P < 0.05$, $\eta^2 = 0.25$. Post hoc analysis yielded similar values between the OL (M = 54.7%, s = 4.2%) and NL groups (M = 53.1%, s = 7.0%) for shots from 6.25 m ($P = 0.43$). In contrast, the percentage of hits across the four blocks was lower in the NL group (M = 28.8%, s = 4.9%) compared to the OL group (M = 49.3%, s = 4.7%) from 6.75 m ($P < 0.001$). The percentage of hits in the OL group was very stable across blocks and distances. The absence of main or interaction effects for block indicates that the position (i.e., the view angle to the backboard and the rim) had no influence on the percentage of hits and, indicates high three-point shot consistency across trials and varying positions. The absence of any block effects further shows that the percentage of hits across the blocks was not influenced by fatigue (or that fatigue was not an issue at all) in the present experiment. Moreover, the non-significant group × distance × block interaction ($P = 0.20$) reveals that the performance of the NL group did not increase across the four blocks from 6.75 m, after the huge decrease in percentage of hits from the last block at 6.25 m (M = 49.0%, s = 2.0%) to the first block at 6.75 m (M = 12.9%, s = 6.6%).

Throwing tendencies

Throwing tendencies are displayed in Figure 3. The analysis of throwing tendencies yielded significant differences between the two distance conditions, $F(1,18) = 26.39$, $P < 0.001$, $\eta^2 = 0.60$, with smaller deviations from zero (i.e., the target) for shots from 6.25 m ($M = -0.28$, SE = 0.11) compared to shots from 6.75 m ($M = -0.64$, SE = 0.13). A group × distance interaction, $F(1,18) = 19.48$, $P < 0.001$, $\eta^2 = 0.52$, revealed that the throwing tendencies were influenced by group affiliation (i.e., the floor markings for shots from 6.75 m) and distance. While throwing tendencies did not differ between the two groups for shots taken from 6.25 m (OL group, $M = -0.24$, SE = 0.18; NL group, $M = -0.33$, SE = 0.13; $P = 0.71$), performance was worse in the NL group compared to the OL group for shots taken from 6.75 m (OL group, $M = -0.29$, SE = 0.17; NL group, $M = -0.99$, SE = 0.13; $P < 0.01$). The analysis also revealed a main effect for block, $F(1,18) = 10.05$, $P < 0.01$, $\eta^2 = 0.36$, with lower values in block 1 ($M = -0.62$, SE = 0.12) than in block 4 ($M = -0.30$, SE = 0.12). Due to the absence of a block × distance interaction, this effect indicates a familiarisation with the task block-by-block (for both

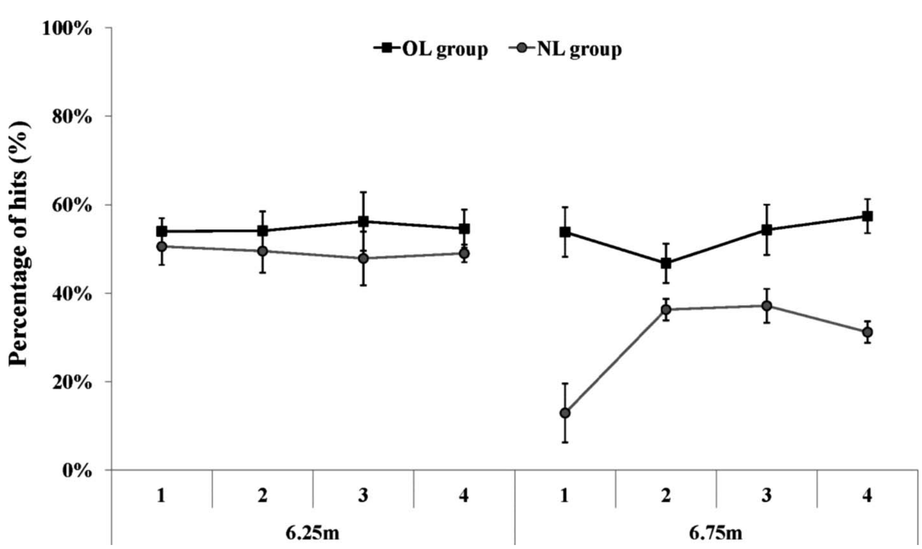

Figure 2. Percentage of hits for the old lines group (OL group; black line and rectangle) and the new lines group (NL group; grey line and circle) across the four blocks for shots taken from 6.25 m and 6.75 m, averaged across the trials of one block. Error bars indicate standard errors.

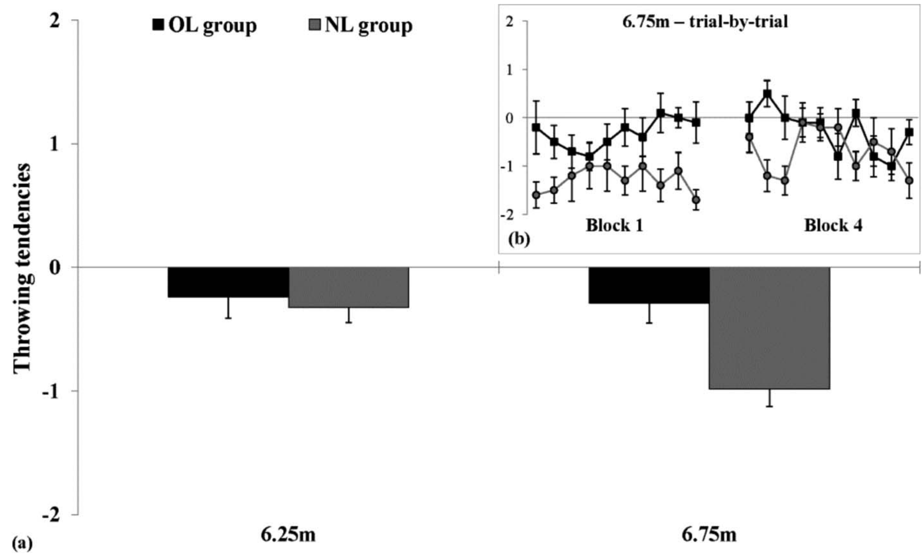

Figure 3. Throwing tendencies for the old lines group (OL group; black bar/ rectangle) and the new lines group (NL group; grey bar/ circle) (a) for shots taken from 6.25 m and 6.75 m averaged across the trials of block 1 and 4, and (b) for each shot of block 1 and 4 from 6.75 m, trial-by-trial. Throwing tendencies are displayed on a 5-point-scale with 0 indicating successful shots without hitting the rim or the backboard, negative values indicating undershooting the basket and positive values indicating overshooting the basket. Error bars indicate standard errors.

distances). This result also provides evidence that fatigue was not an issue in the experiment, because the ball landed closer to the target in later than in earlier blocks. Due to the relatively stable throwing tendencies of the OL group and the absence of a group × distance × block interaction, $F(1,18) = 1.01$, $P = 0.33$, it can be inferred that the reduction of distance error (i.e. undershooting) from the first to the last block for shots taken from 6.75 m was not larger in the NL compared to the OL group, as would be expected from the huge decrement in performance in the NL group for shots taken from the larger distance. Throwing tendencies of the two groups still differed in the last block from 6.75 m ($P < 0.05$).

Throwing tendencies trial-by-trial

Due to the results reported thus far, we performed a trial-by-trial analysis of the throwing tendencies for shots taken from 6.75 m (from Position 1, i.e. block 1 and 4) to test whether or not the NL group gradually adapted to the greater distance. Data analysis revealed group differences across all trials, $F(1,18) = 10.59$, $P < 0.01$, $\eta^2 = 0.37$, with smaller deviations from zero in the OL group ($M = -0.29$, $SE = 0.17$) compared to the NL group ($M = -0.99$, $SE = 0.13$). A group × trial interaction, $F(19,342) = 1.68$, $P < 0.05$, $\eta^2 = 0.09$, indicated high variability between trials with throwing tendencies differing significantly between groups in half of the trials, while in the other half of the trials this was not seen (see Figure 3b). However, post hoc comparisons in both groups could not provide any evidence for significant changes in throwing tendency from one trial to the next (i.e., error-based learning on a trial-by-trial basis). With the absence of a main effect for trial, $F(19,342) = 1.05$, $P = 0.40$, it can be further inferred that there were no changes in throwing tendencies over time for either group. In the case of the OL group this result is reasonable, considering that they had no decrement in throwing tendencies when changing to the greater distance. However, simple comparisons between the throwing tendencies of the first ($M = -1.60$, $SE = 0.27$) and the last shot ($M = -1.30$, $SE = 0.37$) from 6.75 m in the NL group, for example, revealed no significant differences ($P = 0.50$), which further suggests that performance error (on a trial-by-trial basis) for the NL group was not reduced within the series of shots from 6.75 m.

Discussion

We examined the influence of visual context information on skilled motor behaviour, and the extent to which the motor system's ability to rapidly adapt to environmental changes generalises to expert performance. Our data showed that the OL group was as precise with their three-point shots from the greater distance as from the familiar distance, indicating a rapid adaptation to the distance demands beyond the scope of experienced shots. These findings are similar to what was shown for adaptation within familiar distances (de Oliveira et al., 2009). In contrast, the NL group performed worse from 6.75 m compared to 6.25 m. Furthermore, data from the NL group did not reveal statistical evidence for an adaptation within the series of shots from the longer distance. As indicated by the stable throwing tendencies and percentages of hits in the OL group until the last block from 6.75 m, the decrease in performance in the NL group cannot be ascribed to fatigue or a lack of physiological capabilities, as the distance demands were the same for both groups.

With respect to the performance of both groups from the longer distance, our data did not support the theory of de Oliveira et al. (2009) that vision of the basket (e.g., angle of elevation information) is sufficient for distance control in basketball jump-shooting. According to their theory, both groups should have adapted similarly to the longer distance because information from the rim and the backboard were the same in both groups. Our data strongly indicates that the constant properties of the basketball three-point line serve as an important visuo-spatial landmark for three-point shooting in expert basketball players. Thereby, the finding that the OL group rapidly adapted to the longer distance without any decrement in performance underlines the important role of the three-point line (with its constant properties and reliable information) for the calibration of the respective motor commands in expert basketball players. With respect to the deliberate practice approach, which suggests that expert performance is characterised by maximum adaptations to task constraints mediated by deliberate practice (Ericsson & Lehmann, 1996, Ericsson et al., 1993), the three-point line in basketball seems to be one task constraint to which expert performers maximally adapt during years of practice. Fitzpatrick et al. (1982) reported a similar effect for the height of the basket.

With regard to the classification of context information as intentional (i.e., cues that are essential for achieving skilled performance) and incidental cues (i.e., cues that have the potential to become associated with the task) (Wright & Shea, 1991), we agree with de Oliveira et al. (2009) and Keetch et al. (2005), that information about the location of the rim in relation to the own position (of the player) is essential for achieving skilled throwing performance. However, the results of the present experiment are incongruent with Keetch et al. (2005, p. 974), who concluded that "skilled players probably use direct visual information about the distance between their current location and the location of the basketball rim as the primary (and perhaps sole) source of perceptual input for movement preparation." The fact that the NL group was not able to adapt to the longer distance, indicates that the three-point line is an incidental visual cue that becomes associated with the three-point shot due to extensive amounts of practice. Furthermore, we hypothesise that the information from the three-point line is predominantly processed in expert basketball players, when information from the basket (i.e. the intentional cue; cf. de Oliveira et al., 2009) and from the floor markings (i.e. the incidental cue) are available and call for the retrieval of different sets of motor commands. Taken together, our results provide evidence for a prominent role of visual context information for expert performance and motor adaptation.

Based on the present data, we propose that the three-point shot is developed relative to the three-point line due to its constant properties and, with increasing amounts of practice, the three-point line (as an incidental cue) is integrated into the sensorimotor representation as a key stimulus that calls for a specific, presumably conditioned, motor response (cf. Pearce & Hall, 1980; Shiffrin & Schneider, 1977; Treisman & Gelade, 1980). We hypothesise that when an expert player prepares to take a shot behind the three-point line, a readily available signature of motoric-spatial coding (Chieffi & Allport, 1997) developed by years of practice with constant visual context information is retrieved from memory and will only be updated based on the player's own position relative to the three-point line. The three-point line seems to be used as an advanced perceptual cue that calls for a highly automatic motor response, or at least is used for scaling movement parameters (e.g. limb dynamics) to meet the actual demands of the three-point shot by expert basketball players. The translation of such stimuli into appropriate motor responses is thought to underlie highly automatic processes (cf. Hommel, 2009), particularly in expert performers (Ericsson & Lehmann, 1996). Based on that notion, we argue that participants of both the NL and OL group automatically retrieved the (well-established) motor response for the familiar distance and three-point line court markings, and used the visible distance between their own position and the familiar three-point line to scale/update their pre-defined set of motor commands for the three-point shot when required to take shots from the longer distance. This distance between the old and new three-point line was 50 cm in the OL group and 0 cm in the NL group, which resulted in adjustments that were appropriate to deal with the larger distance only in the OL group. In contrast, increasing the distance between the three-point line and the basket in the NL group led to a dramatic decrease in performance for shots taken from 6.75 m, as indicated by the large proportion of trials in which the basket was undershot. This result indicates that the three-point shot was still scaled relative to the familiar dimensions of the three-point line, ignoring the greater distance to the basket. Thus, we suggest that the adaptation of skilled behaviour to changed conditions and constraints is facilitated by providing both old and new visuo-spatial information. This should result in an improved implementation of the new characteristics (e.g. the changed floor-markings, and the larger distance) in motor memory. In how far throwing performance is generally influenced by the lines on the court and, thus, if the lines are essential for successful performance (i.e. being an intentional cue), should be examined in future studies. One way this could be examined is by assessing throwing performance when the lines on the court (e.g. the free-throw line) are displaced to a position closer or farther to the rim, and ensuring that participants are unaware of this manipulation.

However, the extent to which information from the three-point line facilitates the movement execution (so much that it becomes a part of the movement representation during skill acquisition) remains unknown. One reason for choosing the three-point line as a visual reference might be the higher stability of the motor response when using such an advanced perceptual cue, particularly under varying environmental conditions. Because the movement representation must only be updated based on the player's own position relative to the respective (reliable) cue, and not relative to a more distant target, potential visual estimation errors should be lower compared to direct estimation of the distance to the target. This is particularly true when estimating the distance of far away goals, and under varying environmental conditions which might disturb direct distance estimation. In basketball, for example, direct distance estimation could be disturbed by opponents or team-mates that obscure the direct view to the basket. Another reason might be the lower cognitive costs associated with the selection of an appropriate motor response based on advanced perceptual cues which call for a specific motor response. In fact, this reduction in cognitive costs should allow for faster movement initiation, which is especially important in basketball. Since players continuously face pressure from opponents or time, it is advantageous to revert to highly automatic, reliable processes that are initiated within milliseconds. Both explanations are in line with the finding that experts are better than novices at picking up perceptual cues (Mann, Williams, Ward, & Janelle, 2007), and that experts select responses on the basis of advanced perceptual cues (Ericsson & Lehmann, 1996) to increase both the speed and accuracy of motor responses.

From an applied point of view, a number of practical recommendations can be provided for athletes, coaches and governing bodies. With regard to the current rule change in basketball, our data indicates that the new three-point line on the basketball court should be carefully introduced in daily practice. That means that initially the old three-point line should be presented additionally to the new line on the court, when athletes are required to practice three-point shots from 6.75 m (i.e. the longer distance). As athletes become more accustomed to the longer distance, information from the old three-point line can be reduced (e.g., through blocked practice with and without vision of the old three-point line, or reduction of the visibility of the old three-point line) until performance from 6.75 m with only the new lines on the court is as high (and stable) as it was from 6.25 m. Note that this suggestion is somewhat speculative as we only examined short-term adaptation of performance and not long-term training effects. Generally, our findings suggest that athletes can better adapt their performance to changed visual information when the new settings or constraints are presented together with, or in relation to, the well-known, old settings or constraints (until the movement representation is updated according to the new constraints). We speculate that athletes or teams that systematically integrate changed constraints into early practice sessions are probably better able to take advantage of the respective rule change (e.g. through higher performance), in contrast to teams or athletes that focus late and less systematically on such changes.

It is necessary that coaches and athletes are informed about future changes by the respective governing bodies as early as possible to adjust their practice sessions respectively. Moreover, the fact that floor markings deliver information required for successful performance in basketball experts seems to be of high practical relevance for two reasons. First, it is likely that the performance of young athletes can be improved by making them focus early on the three-point line (e.g., through practising three-point shots without late or disturbed vision of the rim). This strategy will help athletes to integrate this cue in the sensorimotor representation of the three-point shot, and result in an improved ability to successfully perform three-point shots even when vision of the basket is disturbed (e.g., by opponents). Second, the influence of the floor markings on throwing performance could result in a better throwing performance on courts where athletes regularly practice due to the familiarity with visual context information on this court. It can be assumed that even little differences concerning the shape of the floor markings, their position, or the state of the surface on other courts, can result in decreased performance. It seems important to practice on different courts in order to be able to flexibly adjust the three-point throwing performance to varying environmental conditions and to reduce the influence of the specific visual context information. However, rule changes occur rather often in sports (e.g. time rules in basketball, ball size in table tennis, tie-break in tennis, sportswear in beach-volleyball and judo, and many others), and are made in large part to make the sport more attractive for the media and spectators. We have doubts that decreased performance as a consequence of changed rules, as shown in the present study for a current rule change in basketball, is an appropriate way towards making the sport more attractive. Governing Bodies would be well advised to carefully explore both the benefits and the costs associated with rule changes before modifying constraints. The influence of the changed rule or rules on athletes' performance and the sport itself should be investigated well in advance, and possibilities for how to deal with basic changes should be reported back to coaches and athletes.

To summarise, our findings indicate that visual context information, like the floor markings in basketball, deliver relevant information that is necessary for successfully performing under unstable environmental conditions, and for adapting to unfamiliar task constraints in experts. For this reason, changing stable context information that is reliably associated with a well-developed motor task can result in erroneous behaviour and a poor adaptation to changed task demands. The findings of the present study underline the important role of task-related visual context information in expert performance, and its adaptation to varying conditions.

Acknowledgements

We thank the staff at Leipzig University for the use of the materials and facilities reported here. We also thank the athletes for their participation in this research, Thorben Schwieder for his assistance in data collection as well as Patricia Land and Charmayne Hughes for helpful comments to improve the quality of the paper. We further thank Mark Williams and two anonymous reviewers for their constructive and helpful comments on earlier versions of the manuscript.

References

Breslin, G., Hodges, N. J., Kennedy, R., Hanlon, M., & Williams, A. M. (2010). An especial skill: Support for a learned parameters hypothesis. *Acta Psychologica*, *134*, 55–60.

Chieffi, S., & Allport, D. A. (1997). Independent coding of target distance and direction in visuo-spatial working memory. *Psychological Research*, *60*, 244–250.

de Oliveira, R. F., Oudejans, R. R. D., & Beek, P. J. (2009). Experts appear to use angle of elevation information in basketball shooting. *Journal of Experimental Psychology*, *35*, 750–761.

Ericsson, K. A., Krampe, R. T., & Tesch-Römer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review*, *100*, 363–406.

Ericsson, K. A., & Lehmann, A. C. (1996). Expert and exceptional performance: Evidence of maximal adaptation to task constraints. *Annual Review of Psychology*, *47*, 273–305.

Fernandez-Ruiz, J., & Diaz, R. (1999). Prism adaptation and aftereffect: Specifying the properties of a procedural memory system. *Learning & Memory*, *6*, 47–53.

Fitzpatrick, V., Pasnak, R., & Tyer, Z. E. (1982). The effect of familiar size at familiar distances. *Perception*, *11*, 85–91.

Hommel, B. (2009). Action control according to TEC (theory of event coding). *Psychological Research*, *73*, 512–526.

Keetch, K. M., Schmidt, R. A., Lee, T. D., & Young, D. E. (2005). Especial skills: Their emergence with massive amounts of practice. *Journal of Experimental Psychology: Human Perception and Performance*, *31*, 970–978.

Krakauer, J. W., Ghilardi, M.-F., & Ghez, C. (1999). Independent learning of internal models for kinematic and dynamic control of reaching. *Nature Neuroscience*, *2*, 1026–1031.

Lackner, J. R., & DiZio, P. (1994). Rapid adaptation to coriolis-force perturbations of arm trajectory. *Journal of Neurophysiology*, *72*, 299–313.

Mann, D. T. Y., Williams, A. M., Ward, P., & Janelle, C. M. (2007). Perceptual-cognitive expertise in sport: A meta-analysis. *Journal of Sport & Exercise Psychology*, *29*, 457–478.

Ooi, T. L., Wu, B., & He, Z. J. J. (2001). Distance determined by the angular declination below the horizon. *Nature*, *414*, 197–200.

Oudejans, R. R. D., van de Langenberg, R. W., & Hutter, R. I. (2002). Aiming at a far target under different viewing conditions: Visual control in basketball jump shooting. *Human Movement Science*, *21*, 457–480.

Pearce, J. M., & Hall, G. (1980). A model for Pavlovian learning – Variations in the effectiveness of conditioned but not of unconditioned stimuli. *Psychological Review*, *87*, 532–552.

Redding, G. M., & Wallace, B. (1993). Adaptive coordination and alignment of eye and hand. *Journal of Motor Behaviour*, *25*, 75–88.

Sarlegna, F. R., Malfait, N., Bringoux, L., Bourdin, C., & Vercher, J. L. (2010). Force-field adaptation without proprioception: Can vision be used to model limb dynamics? *Neuropsychologia*, *48*, 60–67.

Schmidt, R. A. (1975). Schema theory of discrete motor skill learning. *Psychological Review*, *82*, 225-260.

Schmidt, R. A. (2003). Motor schema theory after 27 years: Reflections and implications for a new theory. *Research Quarterly for Exercise and Sport*, *74*, 366–375.

Shadmehr, R., & Mussa-Ivaldi, F. A. (1994). Adaptive representation of dynamics during learning of a motor task. *Journal of Neuroscience*, *14*, 3208–3224.

Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic human information-processing. 2. Perceptual learning, automatic attending, and a general theory. *Psychological Review*, *84*, 127–190.

Treisman, A. M., & Gelade, G. (1980). Feature-integration theory of attention. *Cognitive Psychology*, *12*, 97–136.

Vickers, J. N. (1996). Visual control when aiming at a far target. *Journal of Experimental Psychology – Human Perception and Performance*, *22*, 342–354.

Vickers, J. N. (2009). Advances in coupling perception and action: The quiet eye as a bidirectional link between gaze, attention, and action. *Progress in Brain Research*, *174*, 279–288.

Williams, A. M., Singer, R. N., & Frehlich, S. G. (2002). Quiet eye duration, expertise, and task complexity in near and far aiming tasks. *Journal of Motor Behaviour*, *34*, 197–207.

Wright, D. L., & Shea, C. H. (1991). Contextual dependencies in motor skills. *Memory & Cognition*, *19*, 361–370.