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Does training with 3D videos improve decision making in team invasion sports?

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Abstract

We examined the effectiveness of video-based decision training in national youth handball teams. Extending previous research, we tested in Study 1 whether a three-dimensional (3D) video training group would outperform a two-dimensional (2D) group. In Study 2, a 3D training group was compared to a control group and a group trained with a traditional tactic board. In both studies training was 6 weeks. Performance was measured in a pre–post–retention design. The tests consisted of a decision-making task measuring quality of decisions (first and best option) and decision time (time for first and best option). The results of Study 1 showed learning effects and revealed that the 3D video group made faster first-option choices than the 2D group but differences in the quality of options were not pronounced. The results of Study 2 revealed learning effects for both training groups compared to the control group and faster choices in the 3D group compared to both other groups. Together, the results show that 3D video training is the most useful tool for improving choices in handball, but only in reference to decision time and not decision quality for quick choices in which the stimulus format matters. We discuss the usefulness of a 3D video tool for training of decision-making skills outside the laboratory or gym.

Keyword: training intervention, video, decision making, handball, 3D video training

Experts in sports need perceptual-cognitive expertise (Mann, Williams, Ward, & Janelle, 2007). To be successful, athletes need to know what to look at and when to look at it. They have to extract the meaning of the most information-rich areas of a certain visual display and act appropriately on the information. This combined ability is defined as visual-perceptual-motor skill (Jackson & Farrow, 2005). The training of, for instance, athletes' decision-making skills is a key element of success in sports (Baker, Cote, & Abernethy, 2003). In high-speed interceptive sports such as team handball, choices need to be made very fast because the response window, which is dictated by the speed of the ball and the movements of teammates as well as opponents, is very short (Abernethy, 1991).

Sports provide an excellent opportunity to examine the so-called building blocks of decision making and to gain a better understanding of decision making in general. These building blocks are rules for searching for information, stopping the search, and deciding between two or more options (Raab, 2012). Given the highly dynamic nature of sports settings, it is interesting to see how the search for information and the subsequent choice work together in such settings to influence decision-making quality. Decision-making quality is often described in terms of the quality of the decision (the first or best generated option) and the time needed for the decision (for the first and best option). In a meta-analysis of 42 studies, Mann et al. (2007) quantified the effect of experts having better decision-making skills (e.g., picking up perceptual cues, visual search behaviours) compared to their lesser skilled counterparts due to general training effects as a point-biserial correlation coefficient (r_{pb}) of .31. Further, with a group of experts of various skill levels in handball, Raab and Johnson (2007) provided longitudinal evidence that the first-option quality and choice time of experts were better than those of their lesser skilled counterparts due to training effects. The authors also showed that the visual search behaviour and therefore the acquisition of information differed between expert, near-expert, and nonexpert athletes. Experts required fewer fixations to extract the relevant information. With a group of 74 expert handball players, Glöckner, Heinen, Johnson, and Raab (2012) provided evidence that early fixations are particularly predictive for choices the player will make later. Given that visual search behaviour seems to be an important factor in decision making, the question arises if decision-making skills can be improved by optimizing the search for information. Crucial for the present study is the question of how information search can be facilitated through the use of suitable forms of stimulus presentation.

A recent meta-analysis of 31 studies in sports on decision making in experts added evidence that stimulus presentation is a crucial moderator of previously found expertise differences (Travassos et al., 2013). In this review the authors compared the effectiveness of slide images [two-dimensional (2D) static images], video presentations (2D video presentations of sports scenes), and performance of tasks in situ (natural settings). Results revealed that the in situ condition was the only experimental condition that consistently showed an advantage of experts over novices. Therefore, enhancing stimulus presentation by using more realistic animations might induce faster responses (especially in interceptive sports) as well as higher accuracy because it might be easier for observers to imagine themselves in a real game situation. Finally, in a narrative review, Marasso, Laborde, Bardaglio, and Raab (2014) readdressed the importance of stimulus presentation. The authors indicated that fidelity, that is, the degree to which the simulated environment is comparable to the real game situation (Hays & Singer, 1989), matters, especially when considering applications in the early developmental phases of athletes' training.

The challenge in laboratory studies is to provide visual-perceptual demands in a laboratory that are similar to those encountered in a real game environment. This is an important point because if 2D video projections are used, the visual-perceptual-motor responses elicited may not fully reflect those observed in game situations, because human vision is three dimensional (3D). To provide a 3D perspective, or view, an oblique view of an object or scene is displayed on a computer monitor. When viewed from a certain perspective, even a 2D image can appear to have depth and therefore with the appropriate 3D technology, a 3D view is achieved (St. John, Cowen, Smallman, & Oonk, 2001). With a 3D view, perception of the corresponding affordances is possible, and this is important because it affects which motor action is chosen (Lee et al., 2013). Therefore, to project sport-specific scenarios with realistic scale and depth the use of a 3D stereoscopic system might be useful.

The importance of decision-making skills for athletes is undisputed, but what is known about training to improve decision-making abilities in players in interceptive sports such as handball, and further, what kinds of presentations will be most effective in that training? The short answer is not too much in quantitative terms, as meta-analyses are missing. Experimental evidence from single studies suggests that a 4- to 6-week training module using videotapes can significantly improve response-selection accuracy in American football (Christina, Barresi, & Shaffner, 1990). There is also evidence that the videos used in decision-making training were more effective than static images (Starkes & Lindley, 1994). The efficacy of explicit and implicit perceptual training approaches to improve pattern-perception capabilities in basketball players was investigated by Gorman and Farrow (2009). The authors used temporally occluded video footage or full videos, but no differences were found between the experimental groups. To explore whether videos played at above normal speed are useful for improving decision-making skills, Lorains, Ball, and MacMahon (2013) conducted a study with elite Australian football players. Two experimental video training groups (videos played at fast and normal speed) as well as a control group took part in the 5-

week study. The results provided evidence that (a) a video-based decision-making training is effective in team invasion sports, and (b) training with videos played at above normal speed seems to be more effective than training with normal-speed videos.

There have been studies comparing 2D and 3D displays in other areas, such as medicine and the military, but their results are mixed and fail to establish a clear advantage of 3D displays (Smallman, St. John, Oonk, & Cowen, 2001, p. 3; St. John et al., 2001). The current trend in 3D stimulus presentation has been largely ignored in the domain of sports for decision-making training, although Farrow has done preliminary work (as cited in Farrow & Raab, 2008) with athletes and Put et al. (2014) with referees. In Put et al.'s study, experienced soccer referees showed improvements in offside judgements of about 5% when stimuli were presented in 3D instead of 2D. However, this effect was found only for near distances of 15 m or less and only for dynamic videos and not for a frame-recognition task. Decision time was not collected, but this is important for athletes' choices in highly dynamic team sports (Mann et al., 2007).

Given the evidence of the importance of decision-making skills in invasion sports as indicated in all of the above-cited meta-analyses and individual studies, it is surprising that most of these studies focussed on expert–novice differences. Whether these differences are due to training could be demonstrated if the same devices were used for training and tests. Previous research showed that perceptual training of 4–6 weeks is sufficient to improve performance (e.g., Lorains et al., 2013). Yet although there is growing interest in utilizing virtual environments in the context of sports (Miles, Pop, Watt, Lawrence, & John, 2012), the effectiveness of a video-simulation training to improve the decision-making abilities of athletes is largely unknown. Additionally, it is unknown how much more could be gained if trainers used 3D video instead of classic tools such as 2D stimuli or tactic boards. Even if it is possible to detect expert–novice differences in static and dynamic presentations (e.g., McMorris & Graydon, 1996), it remains an open question whether a 3D presentation might be even more successful in improving decision-making performance. Therefore, we sought to fill the void by extending previous research on the effects of 2D versus 3D stimulus presentation in decision-making training. We compared these effects to benchmarks (i.e., no additional decision training and training with static tactic boards, which represent different game situations on a board by marking the position of different players and the corresponding moves). Thus, the aim of the present study was to improve the stimulus presentations used in decision-making training, which will have practical value in the sports domain.

It should be mentioned that there is an ongoing controversy about whether perceptual training is effective even when action and perception are separated. For instance, there is evidence that perceptual training is effective even when perception and action are separated and that the improvements made through perceptual training can be transferred to real-world situations (Farrow & Abernethy, 2002; Put, Wagemans, Jaspers, & Helsen, 2013). This positive transfer can be explained by the common coding theory (Hommel, Müsseler, Aschersleben, & Prinz, 2001; Prinz, 1997). The common coding theory proposes a common representational mechanism between perception and action. Codes for perception and codes for action are represented within one medium and prime each other. Perceptual training leads to the activation of certain codes for perception that would in turn activate certain action codes. Based on this assumption, we decided to conduct pure perceptual training for improving decision-making abilities.

There are several reasons why a 3D view might be more useful than a 2D view: First, all three dimensions are integrated into a single image; second, this view can provide supplementary depth cues (e.g., shadows); and third, it allow observers to see features of an object that are not visible in a 2D view (St. John et al., 2001). It is possible that the closer to real life the presentation is, the better the performances of the participants after the training will be. We assumed that the more cognitive-processing similarities there are between the training environment and real performance situations, the higher the level of transfer, due to transfer-appropriate processing (Lee, 1988). Therefore, the fidelity of the presentation should be as high as possible to be effective (Stoffregen, Bardy, Smart, & Pagulayan, 2003).

We had several hypotheses regarding decision quality and decision time. First, we expected in both studies to find learning effects (improvements) at posttest that would remain stable to a retention test. Differences between groups should indicate the advantage of 3D training: We expected the 3D training group to outperform the 2D group (Study 1) and a no-training control group and tactic-board training group (Study 2). We hypothesized that the advantage of 3D is conferred by the fidelity of the 3D presentation and the depth information conveyed in the 3D video (Farrow & Raab, 2008). Further, we expected the differences between groups to be stronger for first options than for best options (quality and decision time) because stimulus presentation may influence early information search more strongly than it does the search for additional options, which have been shown to be influenced by memory and association strength as well as specific cognitive strategies (Raab & Johnson, 2007).

Study 1

Methods

Participants. Twenty female handball players (born 1993, National Team C candidates) were recruited to take part in the study. The criteria for inclusion were that all players had the same amount of training during the week (2–4 training sessions per week) and that they had nearly the same performance level.

Apparatus. We used an option-generation paradigm established previously (Johnson & Raab, 2003; Raab & Johnson, 2007) in which participants first have to generate as many appropriate options as possible to solve a certain attacking situation in handball and second must decide which would be the best option. Recently a 3D video display version was shown to be reliable and the fidelity of the experience was validated (Laborde & Raab, 2013; Laborde, Raab, & Kinrade, 2014). In a pilot study, we tested different camera settings (e.g., angle of view) and positions (e.g., distance to the players) on the playing field to find the best way to produce realistic scenes. Similar to Farrow, Rendell and Gorman (2006), we found that the best video perspective was that of a player, from a first-person perspective, who had to pick an option, meaning only parts of the attacking scene were visible. On average four defending and three attacking players were visible in the video.

The aim of a second pilot study was to develop appropriate video material that reflects typical attacking situations in handball. Therefore we asked expert coaches who work with players of a similar performance level about typically offensive and defensive behaviours. On the basis of the results of the interviews, we extracted four prototypical attacking situations and defence formations. We asked players of a similar performance level to the observers in the later study to illustrate these typical game situations. The videos were edited with Windows Movie Maker and Magix Video Deluxe. We used a cinema-like mobile 3D projection system (more3d) to present the videos. This system consists of two projectors, wireless polarization glasses, and a high-performance personal computer. The distance between the observer and the presentation screen was 4 m. We expected that this small distance would contribute to a more natural depth perception. The participant is able to observe more details due to a wider viewing angle (Howard & Rogers, 2002). Additionally, differences between a 2D and a 3D video format can be expected especially in a near condition (Put et al., 2014). The size of the presentation screen was 180 × 240 cm. Later, handball experts rated how realistic these videos were on a Likert scale ranging from 1 (*very realistic*) to 6 (*not realistic*). Only videos that were rated as realistic (score less than 3) were used in the study. We collected data about the quality and timing of the decisions with an interactive voting system (Interactive Voting System, 2009) that consists of a keypad, a receiver, and a notebook computer to process the data.

Procedure and design. Players were assigned to one of the two experimental groups (2D and 3D video group) based on their training day. This was done due to organizational reasons because the test sessions as well as the video training were conducted after the physical training session. To evaluate whether 2D or 3D training is more effective for improving decisions we compared the performance of the two groups with a pretest, after 6 weeks of training with a posttest, and with a retention test 4 weeks after the end of the training. In the pre-, post- and retention tests, 2D and 3D videos of 33 attacking situations with the participant's own team in possession of the ball were presented in random order. The first trial was used to familiarize the participants with the setup. The video sequences were stopped at a point when several options to act were present for the player who was in possession of the ball. In the option-generation paradigm, participants had three tasks: (1) name the first option that came intuitively to mind; (2) name additional options to solve the situation appropriately; and (3) choose the best option among all the verbalized options.

In addition to their regular physical training, both the 3D and the 2D group received 6 weeks of decision training with six training sessions including 64 decision tasks per session and 384 decisions in total. Each training session lasted nearly 30 min per session. No rest periods were incorporated in training or tests sessions. Because the participants were female, the videos showed a women's team at roughly the same expertise level. Appropriate scenarios were extracted on the basis of interviews with the national youth team coaches. Once a week the participants in both training groups saw 64 videos that differed only in whether they were presented in 3D (3D video group) or 2D (2D video group). Four typical offence situations against different defence systems were presented in the videos. During training the participants had to choose one of the presented options as fast as possible. Their answers were collected via the keypad. After the participants had given their answer the video was presented once again. However, this time the entirety of the video was presented to give the participant feedback about the correct solution for the presented situation. To avoid order effects the videos in the training sessions were randomly presented. All groups completed the posttest at the end of training and the retention test 4 weeks later.

Data analysis. We first checked whether data were normally distributed (Kruskal–Wallis test). Because data showed normal distribution we conducted a Group (2D, 3D) × Test (pre, post, retention) analysis of variance (ANOVA) with repeated measures on the latter factor to compare the performance. Additionally, one-way ANOVAs were conducted to examine differences between the groups in pre- ,post- and retention test. Correlations (Pearson) were performed to examine if there is a speed–accuracy trade-off between decision time (freeze frame till first decision) and decision accuracy (quality of first decision). The dependent variables were the quality of the decisions (first option and best option) and the decision time (first and best option).

The quality of decisions was determined by the percentage of correct options generated in each test. Two experts (regional and national coaches) received a list of possible options that were generated by all of the participants, in random order. After the coaches had watched the videos they were asked to evaluate the generated options on a scale from 1 (*not appropriate*) to 6 (*very appropriate*). Additionally, the experts had to identify the best option (see Zastrow, Schlapkohl, & Raab, 2014, for further data regarding the reliability of all dependent variables).

Decision time for the first option was measured via the interactive voting system and controlled for nonintuitive decision making or guessing by using an outlier procedure with a fixed time window (Johnson & Raab, 2003). Post hoc analysis was conducted using the Scheffé test. A significance criterion of $p < .05$ was established for all reported results. Eta-squared values are given for all analyses if F values are larger than 1 to avoid interpretation of random effects. Due to missing values for the retention test, the data of seven players were not included in the analysis. Data are missing because these players did not regularly take part in the additional video training sessions of the current study.

Results

Decision time*.* We assumed a decrease in decision time in both experimental groups as a result of training. A repeated-measure ANOVA indicated that both groups decreased the decision time for the first option, $F(1, 11) = 28.38$; $p < .05$; $\eta^2 = .72$. The 3D group was faster than the 2D group at the posttest, $F(1, 11) = 7.31$; $p < .05$; $\eta^2 = .41$, and at the retention test, $F(1, 11) = 7.31$, $p < .05$; $\eta^2 = .4$. Average decision time for the first option differed between the groups (3D: $M = 2.57$ s; $SD = 0.41$; 2D: $M = 3.05$ s; $SD = 0.16$) and is practically relevant (Figure 1).

<<<<Insert Figure 1 about here>>>

We found a similar effect for best options. Both groups performed faster in the posttest compared to the pretest, $F(1, 11) = 51.61$; $p < .05$; $\eta^2 = .82$. This significant difference was not found in the retention test, $F(1, 11) = 2.00$; $p > .05$; $\eta^2 = .15$. This nonsignificant effect may have been due in part to larger standard deviations, as participants needed on average 10.91 s (*SD* = 1.41) in the 3D group but 12.24 s (*SD* = 2.11) in the 2D group. A difference of 1.5 s in option generation is practically relevant and confirms improvements found in longitudinal studies (Raab & Johnson, 2007).

Option quality. We found no training effects for option quality for first, $F(1,12) = 3.08$; $p > .05$, $\eta^2 = .2$, or best, $F(1,12) = .52$; $p > .05$, $\eta^2 = .04$, options. However, a one-way ANOVA indicated a group difference for first option in the posttest, $F(1, 12) = 9.69$; $p < .05$, $\eta^2 = .46$, as the 3D group increased option quality from pretest to posttest by about 9.21% (*M* = 69.08% correct; *SD* = 5.93), whereas the 2D group increased their performance by only about 7.89% (*M* = 54.37% correct; *SD* = 6.37). In the retention test, the 3D group generated, on average, a higher percentage of correct first options (*M* = 62.5%, *SD* = 9.92) compared to the 2D group (*M* = 58.95%; *SD* = 5.77). This difference of about 4% in retention may need further validation to have practical relevance. However, Put et al. (2014) found about a 5% difference in option quality for 2D versus 3D stimulus presentation in expert referees, and thus small effects may need more powerful designs. Nevertheless it should be noted that whereas percentage of correct responses for first option of the 3D group decreased from posttest to retention test, option quality for first option of the 2D group further increased from posttest to retention test.

The percentage of correct best options between training groups did not differ significantly in the retention test, $F(1,12) = .705$; $p > .05$, $\eta^2 = .06$. The 3D group (*M* = 66.45%; *SD* = 4.82) generated slightly more best options that were correct than the 2D group (*M* =

64.21%; *SD* = 4.4). There were no significant correlations between decision time for first option and quality of first option in the pre-, post- or retention test (*r* = -.10; *r* = -.53; *r* = -.10).

Discussion

In the first study we aimed to evaluate whether it is possible to train decision-making abilities and whether the kind of presentation influences decision time and quality. We assumed that a 3D video would be more effective than a 2D video especially regarding the timing of the decisions because of its higher fidelity. We assumed that both groups would need less time to generate a first option after training. This assumption was confirmed. The 3D group outperformed the 2D group in the posttest and retention test. However, it should be noted that the 3D group already showed a slightly better performance in the pretest. Furthermore, the time between generating the first option and choosing the best option decreased in both groups.

Regarding the quality of options, there was no increase in the percentage of correct first options in either group in the posttest or retention test. Additionally, only a slight trend regarding improvement in terms of the percentage of correct best options was observed in the groups in the posttest and retention test in the 3D group. It is possible that a statistically significant improvement in performance would be found if the training lasted longer.

Taken together, the results indicate that the presentation of a 3D video in training seems to be slightly more effective than the presentation of a 2D video for improving decision time. We assume that the fidelity to real life and the depth information offered by 3D video allowed the participants to put themselves in the game situation (Farrow & Raab, 2008) so that the search for information was facilitated and decisions were faster. To gain further evidence that decision making is facilitated by more lifelike situations and depth information (Hays & Singer, 1989), it would be useful to compare the performance of a 3D video group to that of a group that trained with a traditional tactic board. In contrast to a video presentation, the presentation of game situations on a tactic board is static and much more abstract. Furthermore, the implementation of a control group that does not receive any explicit decision-making training would be useful to control for test effects.

Study 2

The results of Study 1 provided evidence that 3D video simulations of game situations were slightly more effective than 2D videos in improving decision time. The aim of the second study was to compare the performance of a 3D video group with that of a tactic board group and a control group. The question was whether the production of 3D videos is—in light of additional expenses in terms of time, money, and equipment—justifiable when there are much simpler presentation forms.

Methods

Participants. Thirty male handball players (National Team D candidates) between 14 and 16 years old (*M* = 14.89 years; *SD* = 0.75) took part in the present study. Players took part in four training sessions per week. National Team D represents the highest level of regional teams from which higher level national teams are selected.

Apparatus. We used the same equipment for 3D video presentation as in Study 1. This time the scenarios involved male handball players. The tactic board group was trained with a traditional tactic board. These participants saw only static images of the game situations. To give the participants a verbal description of the attacking situation and how the defence was behaving, the experimenter read a text to the participants. They were asked to respond as quickly as possible with what they would do in the situation. As for the video group, the different attacking situations were presented randomly in the six training sessions. All participant received feedback about the correct option. The video groups saw the videos in full length with the correct choices, and the tactic board group received a verbal description of the correct solution and the correct movements of the players were presented visually on the tactic board. The same game situations were used in the 3D video group and the tactic board group.

Procedure. The same procedure as in Study 1 was used. On the basis of the results of the pretest, we assigned the players equally to one of three groups (3D video group, tactic board group, or control group). The criterion for the assignment was the number of correct best decisions. All three groups continued their regular physical training in the gym. The control group received no further (decision) training.

Statistical analysis. We conducted a Group (3D video, tactic board, control) × Test (pre, post, retention) ANOVA with repeated measures on the latter factor with option quality (first option, best option) and decision time (for first and best option) as dependent variables. The same statistical analyses were used as in Study 1.

Results

Decision time. We assumed that the tactic board group and the 3D video group would need less time to identify their first option than the control group after training (i.e., at posttest). Decision time for the first option improved significantly from pretest to posttest for all groups, $F(2, 19) = 38.16$; $p < .05$, $\eta^2 = .8$. All groups improved their performance from pre- to posttest (tactic board group: from 3.26 s, $SD = 1.37$, to 1.45 s, $SD = 0.3$; 3D video group: from 3.14 s, $SD = 1.23$, to 1.45 s, $SD = 0.28$; and control group: from 3.27 s, $SD = 1.33$, to 1.81 s, $SD = 0.32$. An ANOVA revealed a significant difference between the groups, $F(2, 19) = 3.46$; $p = .05$, $\eta^2 = .27$. A post hoc analysis revealed a significant difference between the 3D video group and the control group in the posttest ($p < .05$). However, there was no difference between the tactic board group and the control group in the posttest, $F(1,14) = 2.61$; $p > .05$, $\eta^2 = .05$. Therefore, we confirmed the hypothesis for the 3D video group for the posttest but the differences did not hold at the retention test (see Figure 2).

<<<Insert Figure 2 about here>>>

The results for decision time for best options showed the same pattern as the results for the first option. All groups showed faster decision times in the posttest compared to the pretest, $F(2, 19) = 15.08$; $p < .05$, $\eta^2 = .61$. The 3D video group needed less time in the posttest compared to the control group, $F(2, 19) = 3.56$; $p < .05$, $\eta^2 = .27$. No difference was found between the tactic board group and the control group, $F(2,18) =1.27$; $p > .05$; $\eta^2 = .07$. In contrast to the results for first-option decision time, a significant difference between the groups remained from posttest to retention test, $F(2, 19) = 5.4$; $p < .05$, $\eta^2 = .36$. A post hoc analysis revealed that the 3D video group ($M = 5.91$ s; $SD = 0.47$) needed less time to identify the best option compared to both the control group ($M = 8.86$ s; $SD = 1.04$; $p < .05$) and the tactic board group ($M = 7.55$; $SD = 0.94$), $F(1, 19) = 5.82$; $p < .05$, $\eta^2 = .38$. Whereas the 3D video group needed on average 6.03 s ($SD = 0.49$) in the retention test, the tactic board group needed 8.12 s on average ($SD = 0.75$) and thus this result may have practical significance.

Option quality. As in Study 1, the results for option quality do not reveal meaningful learning effects. Although there was a tendency in all groups to improve in the percentage of correct first options from pretest to posttest, the results were not significant, $F(2, 19) = 3.96$; $p = .06$, $\eta^2 = .17$. There was no difference between the three groups at posttest for first-option quality, $F(2, 19) = 0.33$; $p > .05$, $\eta^2 = .03$. In the retention test there was no difference between the 3D video group and the tactic board group, $F(1,14) = 0.39$; $p > .05$, $\eta^2 = .4$.

For best-option quality, there was no significant difference between the groups from pre- to posttest, $F(2,19) = 0.37$; $p < 0.5$, $\eta^2 = .04$. No difference was found between the tactic board group and the 3D video group in retention test, $F(1,14) = .39$; $p > .05$; $\eta^2 = .05$. However, significant differences can be observed between the groups from posttest to retention test, $F(2, 19) = 5.37$; $p < .05$, $\eta^2 = .36$. Post hoc analyses (Scheffé) revealed significant differences between the tactic board group and the control group ($p < .05$) as well as between the 3D video group and the control group ($p < .05$). There were no correlations between decision time for first option and quality of first option in the pre- and posttest ($r = .20$; $r = -.03$).

Discussion

Our aim in the second study was to compare the effectiveness of 3D video training with (a) training with a tactic board and (b) no specific training in improving decision making. Similar to the results of Raab (2007) and our first study, our findings provide further evidence that decision-making training improves the decision-making abilities of participants. We found that decision time decreased slightly, but the quality of decisions was not improved.

We found a decrease in decision times. The time needed to generate the first option decreased. Participants in the 3D video group made a decision much faster than participants in the control group and the tactic board group at posttest. The results for the time between generating the first option and choosing the best option are similar. The 3D video group needed significantly less time compared to both other groups in the posttest. This time the effect remained at the retention test. Therefore, 3D video training seems to be useful to improve decision times. It is possible that players are better able to put themselves in the game situation when the simulation is more lifelike.

Regarding the quality of the best options, we found a slight increase in performance from pretest to posttest and from posttest to retention test for the tactic board group as well as the 3D video group. This is in line with the results of Raab (2007). With an increase in experience, decision-making abilities improve. Interestingly, whereas the percentage of correct best options increased, the percentage of correct first options did not. Furthermore, there was at least a tendency for the two trainings groups to improve in the percentage of correct first options from pretest to posttest. In the retention test there was no difference between the tactic board group and the 3D video group. However it should be noted that the 3D video group further improved their performance from the posttest to the retention test whereas the tactic board group's performance remained constant.

The reason there are only subtle differences between the two training groups during the training sessions might be the length of the training intervention or the small number of training sessions per week. The growing difference between the two training groups and the control group suggests that a longer training intervention as well as more training sessions per week might be more successful in enhancing decision-making abilities. Further studies should examine whether different and longer training sessions would improve decision-making abilities even more.

General Discussion

In the current studies we first sought to evaluate if it is possible to improve the quality of options and to decrease the time needed to generate appropriate options with specific training in decision-making skills in handball. Faubert (2013) found that expert athletes have learned how to process complex dynamic visual scenes. This ability is one element of their perceptual-cognitive expertise that makes them superior to nonexpert athletes. Therefore, the training of decision-making skills through the presentation of complex sport situations seems to be fruitful.

Second, we sought to evaluate the effectiveness of different types of presentation formats to gain further evidence regarding the influence of depth information and fidelity on decision-making quality and information search (Hays & Singer, 1989). In Study 1 we compared the performance of a 2D video group with that of a 3D video group. In Study 2 we compared the performance of a 3D video group with that of a tactic board group and a control group. In addition to their usual physical training in the gym, all experimental groups completed a decision-making training. In both studies we found that especially the video-based training led to improvements in decision time. However, there was only a tendency for better decisions. One reason the result was not stronger could be that in the training videos, players exhibited a similar level of expertise to that of the observers. Therefore it could be that the observers were already familiar with the presented options for solving the situations. Additionally, feedback was limited to the options generated in the video sequences. Decision-making quality might have been improved even more if players at an advanced level had been displayed providing different solutions or if feedback had been provided by experts about further possible solutions to the task.

Although there are known advantages of 3D views, as described above, there are also some limitations (St John et al., 2001) that might have been responsible for the present results. First, the location of players might have been ambiguous because of certain lines of sight into the viewing plane. Therefore, the angle from which the scenes were viewed may have obscured the location of some players (St. John et al., 2001). Second, in a 3D view there is an asymmetric compression of space that results in the distortion of distances and angles.

Third, the projection of players is compressed toward the line of sight in a 3D view (Sedgwick, 1986, in St. John et al., 2001). It is possible that the observers had misperceived the presented situation.

Even if the benefits of video-based decision training seem to be small, the improvement in reaction time can make a difference. Interestingly, in both studies the slight improvement in decision time does not account for decision quality; that is, decisions did not get worse because the participants took less time for the first decision. Also improvement in time to recognize the best option is not applicable to the game situation but is an important indicator of decision quality (Johnson & Raab, 2003). It is assumed that players with more experience and higher self-efficacy belief more often name their first decision as the best decision (Hepler & Feltz, 2012). According to the take-the-first heuristic, players pick the first decision that comes to mind, and the longer they generate less appropriate options the worse performance gets (Johnson & Raab, 2003). If the time to recognize the best option is improved, the chance that the player will pick the first generated or early generated appropriate option will increase. This decision quality can have practical relevance. However, the small improvement in decision quality was unexpected. Future research should examine whether manipulating elements other than presentation format would improve decision-making quality. For example, feedback could be given by an experienced coach or the videos could show players who are more experienced than the observers.

Additionally, further research can address the question of whether visual search behaviour might change due to a 3D video training. As described above, experts require fewer fixations to extract the relevant information (Johnson & Raab, 2007). Research has already provided evidence that visual search behaviour differs in 2D and 3D presentation conditions (Lee et al., 2013). Participants fixated less on the body of an opponent if they had to respond to his movements in a 3D compared to a 2D condition. Interestingly, performance did not decrease. It can be concluded that more meaningful information per fixation can be provided by 3D depth cues. It would be interesting to see if visual search behaviour can be improved even more by the presentation of 3D video to 2D videos. Nevertheless, the training method presented here can be used outside the gym and has further potential for in-home use or training during recovery from injuries.

However, there are several limitations regarding the present studies. First, it should be noted that often there is not only one correct decision for a given attacking situation. Experts rated the videos and therefore what was considered a correct decision was subjective. Furthermore, what decision is correct highly depends on the technical skills of the player, as well. Second, in our studies the participants had to simply give a verbal response or give their response via a finger press on a keypad. As mentioned above, there is an ongoing controversy about whether a pure perceptual training is effective at all. There is evidence that the pickup of information differs between perception-only and perceptual-motor tasks (Dicks, Button, & Davids, 2010) and that perception–action coupling is one important variable that distinguishes between experts and novices (Travassos et al., 2013). Additionally, Marasso et al. (2014) as well as Put et al. (2014) pointed out that fidelity is an important factor in decision-making paradigms. The similarity between the training task and the real task should be as high as possible to be most effective (Hays & Singer, 1989). One important factor is to use life-like video simulations as in the present study. Another important factor is the kind of response required of the participants.

In their reviews, Travassos et al. (2014) and Marasso et al. (2014) discussed the response type as an important factor that influences the interpretation of expertise choices. For instance, Roca, Williams, and Ford (2014), in a study with skilled soccer players, found that participants who had to move to give a response (acting as in a real soccer match) generated a greater number of verbal report statements than did participants who remained stationary in a seated position. Furthermore, a recent study showed the influence of individuals' motor competence and choices in video-based decision-making assessments (Bruce, Farrow, Raynor, & Mann, 2012). Additionally, Raab (2005) pointed out that for successful performance, the athlete has to simultaneously decide what movement to perform (declarative knowledge) and how (procedural knowledge) it should be executed. Therefore, the separation of decision ("what") and behavioural ("how") training does not seem advisable.

Taken together, our results indicate that a 3D video presentation might be more effective in improving decision time than a 2D video presentation or a presentation with a tactic board. There are several promising research lines for the future. First, it could be examined if the 3D decision-training tool can be used as a diagnostic tool to differentiate between experts and novices (Faubert, 2013) as well as to identify talent. Second, future research should focus on the optimal amount and timing of additional video decision-making training to achieve even clearer results regarding decision quality. Third, applying time pressure to decision making seems to improve decision accuracy (Johnson, 2006). It would be interesting to examine if decision training over a longer period of time under time pressure would be even more effective than training without time pressure. Fourth, research could focus on the question of how feedback could be implemented more effectively to improve not only decision time but also the quality of decisions. Fifth, one important aspect in any training intervention is how the performance improvements in training can be transferred to real match situations. Therefore, in further studies a transfer test will be useful. A good possibility is provided by Lorains et al. (2013). They evaluated decision-making abilities of Australian football players before and after video-based decision training in real game situations.

Handball players as well as all team players in sports need to decide fast. It seems that physical training may have reached its limits. However, the improvement of the perceptual-cognitive skills of athletes, such as decision-making ability, seems to be a useful resource to improve performance of athletes further.

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Figure 1