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3 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

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

49 Sports provide an excellent opportunity to examine the so-called building blocks of  
50 decision making and to gain a better understanding of decision making in general. These  
51 building blocks are rules for searching for information, stopping the search, and deciding  
52 between two or more options (Raab, 2012). Given the highly dynamic nature of sports  
53 settings, it is interesting to see how the search for information and the subsequent choice  
54 work together in such settings to influence decision-making quality. Decision-making quality  
55 is often described in terms of the quality of the decision (the first or best generated option)  
56 and the time needed for the decision (for the first and best option). In a meta-analysis of 42  
57 studies, Mann et al. (2007) quantified the effect of experts having better decision-making  
58 skills (e.g., picking up perceptual cues, visual search behaviours) compared to their lesser  
59 skilled counterparts due to general training effects as a point-biserial correlation coefficient  
60 ( $r_{pb}$ ) of .31. Further, with a group of experts of various skill levels in handball, Raab and  
61 Johnson (2007) provided longitudinal evidence that the first-option quality and choice time  
62 of experts were better than those of their lesser skilled counterparts due to training effects.  
63 The authors also showed that the visual search behaviour and therefore the acquisition of

64 information differed between expert, near-expert, and nonexpert athletes. Experts required  
65 fewer fixations to extract the relevant information. With a group of 74 expert handball  
66 players, Glöckner, Heinen, Johnson, and Raab (2012) provided evidence that early fixations  
67 are particularly predictive for choices the player will make later. Given that visual search  
68 behaviour seems to be an important factor in decision making, the question arises if  
69 decision-making skills can be improved by optimizing the search for information. Crucial for  
70 the present study is the question of how information search can be facilitated through the  
71 use of suitable forms of stimulus presentation.

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

86         The challenge in laboratory studies is to provide visual-perceptual demands in a  
87 laboratory that are similar to those encountered in a real game environment. This is an

88 important point because if 2D video projections are used, the visual-perceptual-motor  
89 responses elicited may not fully reflect those observed in game situations, because human  
90 vision is three dimensional (3D). To provide a 3D perspective, or view, an oblique view of an  
91 object or scene is displayed on a computer monitor. When viewed from a certain  
92 perspective, even a 2D image can appear to have depth and therefore with the appropriate  
93 3D technology, a 3D view is achieved (St. John, Cowen, Smallman, & Oonk, 2001). With a 3D  
94 view, perception of the corresponding affordances is possible, and this is important because  
95 it affects which motor action is chosen (Lee et al., 2013). Therefore, to project sport-specific  
96 scenarios with realistic scale and depth the use of a 3D stereoscopic system might be useful.

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

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

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

126         Given the evidence of the importance of decision-making skills in invasion sports as  
127 indicated in all of the above-cited meta-analyses and individual studies, it is surprising that  
128 most of these studies focussed on expert–novice differences. Whether these differences are  
129 due to training could be demonstrated if the same devices were used for training and tests.  
130 Previous research showed that perceptual training of 4–6 weeks is sufficient to improve  
131 performance (e.g., Lorains et al., 2013). Yet although there is growing interest in utilizing  
132 virtual environments in the context of sports (Miles, Pop, Watt, Lawrence, & John, 2012), the  
133 effectiveness of a video-simulation training to improve the decision-making abilities of  
134 athletes is largely unknown. Additionally, it is unknown how much more could be gained if  
135 trainers used 3D video instead of classic tools such as 2D stimuli or tactic boards. Even if it is

136 possible to detect expert–novice differences in static and dynamic presentations (e.g.,  
137 McMorris & Graydon, 1996), it remains an open question whether a 3D presentation might  
138 be even more successful in improving decision-making performance. Therefore, we sought  
139 to fill the void by extending previous research on the effects of 2D versus 3D stimulus  
140 presentation in decision-making training. We compared these effects to benchmarks (i.e., no  
141 additional decision training and training with static tactic boards, which represent different  
142 game situations on a board by marking the position of different players and the  
143 corresponding moves). Thus, the aim of the present study was to improve the stimulus  
144 presentations used in decision-making training, which will have practical value in the sports  
145 domain.

146         It should be mentioned that there is an ongoing controversy about whether  
147 perceptual training is effective even when action and perception are separated. For instance,  
148 there is evidence that perceptual training is effective even when perception and action are  
149 separated and that the improvements made through perceptual training can be transferred  
150 to real-world situations (Farrow & Abernethy, 2002; Put, Wagemans, Jaspers, & Helsen,  
151 2013). This positive transfer can be explained by the common coding theory (Hommel,  
152 Müsseler, Aschersleben, & Prinz, 2001; Prinz, 1997). The common coding theory proposes a  
153 common representational mechanism between perception and action. Codes for perception  
154 and codes for action are represented within one medium and prime each other. Perceptual  
155 training leads to the activation of certain codes for perception that would in turn activate  
156 certain action codes. Based on this assumption, we decided to conduct pure perceptual  
157 training for improving decision-making abilities.

158         There are several reasons why a 3D view might be more useful than a 2D view: First,  
159 all three dimensions are integrated into a single image; second, this view can provide

160 supplementary depth cues (e.g., shadows); and third, it allow observers to see features of an  
161 object that are not visible in a 2D view (St. John et al., 2001). It is possible that the closer to  
162 real life the presentation is, the better the performances of the participants after the  
163 training will be. We assumed that the more cognitive-processing similarities there are  
164 between the training environment and real performance situations, the higher the level of  
165 transfer, due to transfer-appropriate processing (Lee, 1988). Therefore, the fidelity of the  
166 presentation should be as high as possible to be effective (Stoffregen, Bardy, Smart, &  
167 Pagulayan, 2003).

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

## 180 Study 1

### 181 Methods

182 **Participants.** Twenty female handball players (born 1993, National Team C  
183 candidates) were recruited to take part in the study. The criteria for inclusion were that all

184 players had the same amount of training during the week (2–4 training sessions per week)  
185 and that they had nearly the same performance level.

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

197         The aim of a second pilot study was to develop appropriate video material that  
198 reflects typical attacking situations in handball. Therefore we asked expert coaches who  
199 work with players of a similar performance level about typically offensive and defensive  
200 behaviours. On the basis of the results of the interviews, we extracted four prototypical  
201 attacking situations and defence formations. We asked players of a similar performance level  
202 to the observers in the later study to illustrate these typical game situations. The videos  
203 were edited with Windows Movie Maker and Magix Video Deluxe. We used a cinema-like  
204 mobile 3D projection system (more3d) to present the videos. This system consists of two  
205 projectors, wireless polarization glasses, and a high-performance personal computer. The  
206 distance between the observer and the presentation screen was 4 m. We expected that this  
207 small distance would contribute to a more natural depth perception. The participant is able

208 to observe more details due to a wider viewing angle (Howard & Rogers, 2002). Additionally,  
209 differences between a 2D and a 3D video format can be expected especially in a near  
210 condition (Put et al., 2014). The size of the presentation screen was 180 × 240 cm. Later,  
211 handball experts rated how realistic these videos were on a Likert scale ranging from 1 (*very*  
212 *realistic*) to 6 (*not realistic*). Only videos that were rated as realistic (score less than 3) were  
213 used in the study. We collected data about the quality and timing of the decisions with an  
214 interactive voting system (Interactive Voting System, 2009) that consists of a keypad, a  
215 receiver, and a notebook computer to process the data.

216 **Procedure and design.** Players were assigned to one of the two experimental groups  
217 (2D and 3D video group) based on their training day. This was done due to organizational  
218 reasons because the test sessions as well as the video training were conducted after the  
219 physical training session. To evaluate whether 2D or 3D training is more effective for  
220 improving decisions we compared the performance of the two groups with a pretest, after 6  
221 weeks of training with a posttest, and with a retention test 4 weeks after the end of the  
222 training. In the pre-, post- and retention tests, 2D and 3D videos of 33 attacking situations  
223 with the participant's own team in possession of the ball were presented in random order.  
224 The first trial was used to familiarize the participants with the setup. The video sequences  
225 were stopped at a point when several options to act were present for the player who was in  
226 possession of the ball. In the option-generation paradigm, participants had three tasks: (1)  
227 name the first option that came intuitively to mind; (2) name additional options to solve the  
228 situation appropriately; and (3) choose the best option among all the verbalized options.

229 In addition to their regular physical training, both the 3D and the 2D group received 6  
230 weeks of decision training with six training sessions including 64 decision tasks per session  
231 and 384 decisions in total. Each training session lasted nearly 30 min per session. No rest

232 periods were incorporated in training or tests sessions. Because the participants were  
233 female, the videos showed a women's team at roughly the same expertise level. Appropriate  
234 scenarios were extracted on the basis of interviews with the national youth team coaches.  
235 Once a week the participants in both training groups saw 64 videos that differed only in  
236 whether they were presented in 3D (3D video group) or 2D (2D video group). Four typical  
237 offence situations against different defence systems were presented in the videos. During  
238 training the participants had to choose one of the presented options as fast as possible.  
239 Their answers were collected via the keypad. After the participants had given their answer  
240 the video was presented once again. However, this time the entirety of the video was  
241 presented to give the participant feedback about the correct solution for the presented  
242 situation. To avoid order effects the videos in the training sessions were randomly  
243 presented. All groups completed the posttest at the end of training and the retention test 4  
244 weeks later.

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

254 The quality of decisions was determined by the percentage of correct options  
255 generated in each test. Two experts (regional and national coaches) received a list of

256 possible options that were generated by all of the participants, in random order. After the  
257 coaches had watched the videos they were asked to evaluate the generated options on a  
258 scale from 1 (*not appropriate*) to 6 (*very appropriate*). Additionally, the experts had to  
259 identify the best option (see Zastrow, Schlapkohl, & Raab, 2014, for further data regarding  
260 the reliability of all dependent variables).

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

## 269 Results

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

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

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

287 **Option quality.** We found no training effects for option quality for first,  $F(1,12) =$   
288  $3.08; p > .05, \eta^2 = .2$ , or best,  $F(1,12) = .52; p > .05, \eta^2 = .04$ , options. However, a one-way  
289 ANOVA indicated a group difference for first option in the posttest,  $F(1, 12) = 9.69; p < .05,$   
290  $\eta^2 = .46$ , as the 3D group increased option quality from pretest to posttest by about 9.21%  
291 ( $M = 69.08\%$  correct;  $SD = 5.93$ ), whereas the 2D group increased their performance by only  
292 about 7.89% ( $M = 54.37\%$  correct;  $SD = 6.37$ ). In the retention test, the 3D group generated,  
293 on average, a higher percentage of correct first options ( $M = 62.5\%$ ,  $SD = 9.92$ ) compared to  
294 the 2D group ( $M = 58.95\%$ ;  $SD = 5.77$ ). This difference of about 4% in retention may need  
295 further validation to have practical relevance. However, Put et al. (2014) found about a 5%  
296 difference in option quality for 2D versus 3D stimulus presentation in expert referees, and  
297 thus small effects may need more powerful designs. Nevertheless it should be noted that  
298 whereas percentage of correct responses for first option of the 3D group decreased from  
299 posttest to retention test, option quality for first option of the 2D group further increased  
300 from posttest to retention test.

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

304 64.21%;  $SD = 4.4$ ). There were no significant correlations between decision time for first  
305 option and quality of first option in the pre-, post- or retention test ( $r = -.10$ ;  $r = -.53$ ;  $r = -$   
306  $.10$ ).

### 307 **Discussion**

308 In the first study we aimed to evaluate whether it is possible to train decision-making  
309 abilities and whether the kind of presentation influences decision time and quality. We  
310 assumed that a 3D video would be more effective than a 2D video especially regarding the  
311 timing of the decisions because of its higher fidelity. We assumed that both groups would  
312 need less time to generate a first option after training. This assumption was confirmed. The  
313 3D group outperformed the 2D group in the posttest and retention test. However, it should  
314 be noted that the 3D group already showed a slightly better performance in the pretest.  
315 Furthermore, the time between generating the first option and choosing the best option  
316 decreased in both groups.

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

322 Taken together, the results indicate that the presentation of a 3D video in training  
323 seems to be slightly more effective than the presentation of a 2D video for improving  
324 decision time. We assume that the fidelity to real life and the depth information offered by  
325 3D video allowed the participants to put themselves in the game situation (Farrow & Raab,  
326 2008) so that the search for information was facilitated and decisions were faster. To gain  
327 further evidence that decision making is facilitated by more lifelike situations and depth

328 information (Hays & Singer, 1989), it would be useful to compare the performance of a 3D  
329 video group to that of a group that trained with a traditional tactic board. In contrast to a  
330 video presentation, the presentation of game situations on a tactic board is static and much  
331 more abstract. Furthermore, the implementation of a control group that does not receive  
332 any explicit decision-making training would be useful to control for test effects.

## 333 **Study 2**

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

## 340 **Methods**

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

345 **Apparatus.** We used the same equipment for 3D video presentation as in Study 1.  
346 This time the scenarios involved male handball players. The tactic board group was trained  
347 with a traditional tactic board. These participants saw only static images of the game  
348 situations. To give the participants a verbal description of the attacking situation and how  
349 the defence was behaving, the experimenter read a text to the participants. They were  
350 asked to respond as quickly as possible with what they would do in the situation. As for the  
351 video group, the different attacking situations were presented randomly in the six training

352 sessions. All participant received feedback about the correct option. The video groups saw  
353 the videos in full length with the correct choices, and the tactic board group received a  
354 verbal description of the correct solution and the correct movements of the players were  
355 presented visually on the tactic board. The same game situations were used in the 3D video  
356 group and the tactic board group.

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

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

## 366 Results

367 **Decision time.** We assumed that the tactic board group and the 3D video group  
368 would need less time to identify their first option than the control group after training (i.e.,  
369 at posttest). Decision time for the first option improved significantly from pretest to posttest  
370 for all groups,  $F(2, 19) = 38.16; p < .05, \eta^2 = .8$ . All groups improved their performance from  
371 pre- to posttest (tactic board group: from 3.26 s,  $SD = 1.37$ , to 1.45 s,  $SD = 0.3$ ; 3D video  
372 group: from 3.14 s,  $SD = 1.23$ , to 1.45 s,  $SD = 0.28$ ; and control group: from 3.27 s,  $SD = 1.33$ ,  
373 to 1.81 s,  $SD = 0.32$ . An ANOVA revealed a significant difference between the groups,  $F(2, 19)$   
374  $= 3.46; p = .05, \eta^2 = .27$ . A post hoc analysis revealed a significant difference between the 3D  
375 video group and the control group in the posttest ( $p < .05$ ). However, there was no

376 difference between the tactic board group and the control group in the posttest,  $F(1,14) =$   
377  $2.61; p > .05, \eta^2 = .05$ . Therefore, we confirmed the hypothesis for the 3D video group for the  
378 posttest but the differences did not hold at the retention test (see Figure 2).

379

380 <<<Insert Figure 2 about here>>>

381

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

395 **Option quality.** As in Study 1, the results for option quality do not reveal meaningful  
396 learning effects. Although there was a tendency in all groups to improve in the percentage of  
397 correct first options from pretest to posttest, the results were not significant,  $F(2, 19) = 3.96;$   
398  $p = .06, \eta^2 = .17$ . There was no difference between the three groups at posttest for first-

399 option quality,  $F(2, 19) = 0.33$ ;  $p > .05$ ,  $\eta^2 = .03$ . In the retention test there was no difference  
400 between the 3D video group and the tactic board group,  $F(1,14) = 0.39$ ;  $p >.05$ ,  $\eta^2 = .4$ .

401 For best-option quality, there was no significant difference between the groups from  
402 pre- to posttest,  $F(2,19) = 0.37$ ;  $p < 0.5$ ,  $\eta^2 = .04$ . No difference was found between the tactic  
403 board group and the 3D video group in retention test,  $F(1,14) = .39$ ;  $p > .05$ ;  $\eta^2 = .05$ .

404 However, significant differences can be observed between the groups from posttest to  
405 retention test,  $F(2, 19) = 5.37$ ;  $p < .05$ ,  $\eta^2 = .36$ . Post hoc analyses (Scheffé) revealed  
406 significant differences between the tactic board group and the control group ( $p < .05$ ) as well  
407 as between the 3D video group and the control group ( $p < .05$ ). There were no correlations  
408 between decision time for first option and quality of first option in the pre- and posttest ( $r =$   
409  $.20$ ;  $r = -.03$ ).

## 410 Discussion

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

417 We found a decrease in decision times. The time needed to generate the first option  
418 decreased. Participants in the 3D video group made a decision much faster than participants  
419 in the control group and the tactic board group at posttest. The results for the time between  
420 generating the first option and choosing the best option are similar. The 3D video group  
421 needed significantly less time compared to both other groups in the posttest. This time the  
422 effect remained at the retention test. Therefore, 3D video training seems to be useful to



447 element of their perceptual-cognitive expertise that makes them superior to nonexpert  
448 athletes. Therefore, the training of decision-making skills through the presentation of  
449 complex sport situations seems to be fruitful.

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

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

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

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

490 Additionally, further research can address the question of whether visual search  
491 behaviour might change due to a 3D video training. As described above, experts require  
492 fewer fixations to extract the relevant information (Johnson & Raab, 2007). Research has  
493 already provided evidence that visual search behaviour differs in 2D and 3D presentation  
494 conditions (Lee et al., 2013). Participants fixated less on the body of an opponent if they had

495 to respond to his movements in a 3D compared to a 2D condition. Interestingly,  
496 performance did not decrease. It can be concluded that more meaningful information per  
497 fixation can be provided by 3D depth cues. It would be interesting to see if visual search  
498 behaviour can be improved even more by the presentation of 3D video to 2D videos.  
499 Nevertheless, the training method presented here can be used outside the gym and has  
500 further potential for in-home use or training during recovery from injuries.

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

516           In their reviews, Travassos et al. (2014) and Marasso et al. (2014) discussed the  
517 response type as an important factor that influences the interpretation of expertise choices.  
518 For instance, Roca, Williams, and Ford (2014), in a study with skilled soccer players, found

519 that participants who had to move to give a response (acting as in a real soccer match)  
520 generated a greater number of verbal report statements than did participants who remained  
521 stationary in a seated position. Furthermore, a recent study showed the influence of  
522 individuals' motor competence and choices in video-based decision-making assessments  
523 (Bruce, Farrow, Raynor, & Mann, 2012). Additionally, Raab (2005) pointed out that for  
524 successful performance, the athlete has to simultaneously decide what movement to  
525 perform (declarative knowledge) and how (procedural knowledge) it should be executed.  
526 Therefore, the separation of decision ("what") and behavioural ("how") training does not  
527 seem advisable.

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

## Video-based decision-making training

543 abilities of Australian football players before and after video-based decision training in real  
544 game situations.

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

549

550

551 References

552 Abernethy, B. (1991). Visual search strategies and decision-making in sport. *International*  
553 *Journal of Sport Psychology*, *22*, 189–210.

554 Baker, J., Cote, J., & Abernethy, B. (2003). Sport-specific practice and the development of  
555 expert decision-making in team ball sports. *Journal of Applied Sport Psychology*, *15*,  
556 12–25.

557 Bruce, L., Farrow, D., Raynor, A., & Mann, D. (2012). But I can't pass that far! The influence of  
558 motor skill on decision making. *Psychology of Sport and Exercise*, *13*, 152–161.

559 Christina, R. W., Barresi, J. V., & Shaffner, P. (1990). The development of response selection  
560 accuracy in a football linebacker using video training. *The Sport Psychologist*, *4*, 11–  
561 17.

562 Dicks, M., Button, C., & Davids, K. (2010). Examination of gaze behaviors under in situ and  
563 video simulation task constraints reveals differences in information pickup for  
564 perception and action. *Attention, Perception & Psychophysics*, *72*, 706–720.

565 Farrow, D., & Raab, M. (2008). A recipe for expert decision making. In D. Farrow, J. Baker, &  
566 C. MacMahon (Eds.), *Developing sport expertise: Researchers and coaches put theory*  
567 *into practice* (pp. 137–154). London, England: Routledge.

568 Farrow, D., Rendell, M., & Gorman, A. (2006). *Enhancing the reality of a visual simulation: Is*  
569 *depth information important? Final report*. Canberra, Australia: Australian Institute of  
570 Sport.

571 Faubert, J. (2013). Professional athletes have extraordinary skills for rapidly learning complex  
572 and neutral dynamic visual scenes. *Scientific Reports*, *3* (Article no. 1154).

573 Glöckner, A., Heinen, T., Johnson, J. G., & Raab, M. (2012). Network approaches for expert  
574 decisions in sports. *Human Movement Science*, *31*, 318–333.

- 575 Gorman, A. D., & Farrow, D. (2009). Perceptual training using explicit and implicit  
576 instructional techniques: Does it benefit skilled performers? *International Journal of*  
577 *Sports Science & Coaching*, 4, 193–208.
- 578 Hays, R., & Singer, M. (1989). *Simulation fidelity in training system design: Bridging the gap*  
579 *between reality and training*. New York, NY: Springer.
- 580 Hepler, T. J., & Feltz, D. L. (2012). Take the first heuristic, self-efficacy, and decision-making  
581 in sport. *Journal of Experimental Psychology: Applied*, 18, 154–161.
- 582 Hommel, B., Müsseler, J., Aschersleben, G., & Prinz, W. (2001). The theory of event coding  
583 (TEC): A framework for perception and action planning. *Behavioral and Brain*  
584 *Sciences*, 24, 849–878.
- 585 Howard, I. P., & Rogers, B. J. (2002). *Seeing in depth*. Toronto, ON: I. Porteous.
- 586 Interactive Voting System. (2009). *Handbuch*. Retrieved from  
587 [http://www.ivsystem.nl/downloads/manuals/deutsch/handbuch\\_pro\\_44.pdf](http://www.ivsystem.nl/downloads/manuals/deutsch/handbuch_pro_44.pdf)
- 588 Jackson, R. C., & Farrow, D. (2005). Implicit perceptual training: How, when, and why?  
589 *Human Movement Science*, 24, 308–325.
- 590 Johnson, J. G. (2006). Cognitive modeling of decision making in sports. *Psychology of Sport*  
591 *and Exercise*, 7, 631–652.
- 592 Johnson, J. G., & Raab, M. (2003). Take the first: Option-generation and resulting choices.  
593 *Organizational Behavior and Human Decision Processes*, 91, 215–229.
- 594 Laborde, S., & Raab, M. (2013). The tale of hearts and reason: The influence of mood on  
595 decision making. *Journal of Sport & Exercise Psychology*, 35, 339–357.
- 596 Laborde, S., Raab, M., & Kinrade, N. P. (2014). Is the ability to keep your mind sharp under  
597 pressure reflected in your heart? Evidence for the neurophysiological bases of  
598 decision reinvestment. *Biological Psychology*, 100, 34–42.

- 599 Lee, T. (1988). Transfer-appropriate processing: A framework for conceptualizing practice  
600 effects in motor learning. In O. G. Meijer & K. Roth (Eds.), *Advances in psychology* (pp.  
601 201–215). New York, NY: Elsevier.
- 602 Lee, M. J. C., Tidman, S. J., Lay, B. S., Bourke, P. D., Lloyd, D. G., & Alderson, J. A. (2013).  
603 Visual search differs but not reaction time when intercepting a 3D versus 2D videoed  
604 opponent. *Journal of Motor Behavior*, *45*, 107–115.
- 605 Lorains, M., Ball, K., & MacMahon, C. (2013). An above real time training intervention for  
606 sport decision making. *Psychology of Sport and Exercise*, *14*, 670–674.
- 607 Mann, D. T. Y., Williams, A. M., Ward, P., & Janelle, C. M. (2007). Perceptual-cognitive  
608 expertise in sport: A meta-analysis. *Journal of Sport & Exercise Psychology*, *29*, 457–  
609 478.
- 610 Marasso, D., Laborde, S., Bardaglio, G., & Raab, M. (2014). A developmental perspective on  
611 decision making in sports. *International Review of Sport and Exercise Psychology*, *7*,  
612 1–23.
- 613 McMorris, T., & Graydon, J. (1996). The effect of exercise on the decision-making  
614 performance of experienced and inexperienced soccer players. *Research Quarterly*  
615 *for Exercise and Sport*, *67*, 109–114.
- 616 Miles, H. C., Pop, S. R., Watt, S. J., Lawrence, G. P., & John, N. W. (2012). A review of virtual  
617 environments for training in ball sports. *Computers & Graphics*, *36*, 714–726.
- 618 Murgia, M., Sors, F., Muroni, A. F., Santoro, I., Prpic, V., Galmonte, A., & Agostini, T. (2014).  
619 Using perceptual home-training to improve anticipation skills of soccer goalkeepers.  
620 *Psychology of Sport and Exercise*, *15*, 642–648.
- 621 Prinz, W. (1997). Perception and action planning. *European Journal of Cognitive Psychology*,  
622 *9*, 129–154.

- 623 Put, K., Wagemans, J., Jaspers, A., & Helsen, W. F. (2013). Web-based training improves on-  
624 field offside decision-making performance. *Psychology of Sport and Exercise, 14*, 577–  
625 585.
- 626 Put, K., Wagemans, J., Spitz, J., Armenteros Gallardo, M., Williams, A. M., & Helsen, W. F.  
627 (2014). The use of 2D and 3D information in a perceptual-cognitive judgement task.  
628 *Journal of Sports Sciences, 32*, 1688–1697.
- 629 Raab, M. (2012). Simple heuristics in sports. *International Review of Sport and Exercise*  
630 *Psychology, 5*, 104–120.
- 631 Raab, M., & Johnson, J. (2007). Expertise-based differences in search and option-generation  
632 strategies. *Journal of Experimental Psychology: Applied, 13*, 158–170.
- 633 Raab, M., Masters, R. S., & Maxwell, J. P. (2005). Improving the ‘how’ and ‘what’ decisions of  
634 elite table tennis players. *Human Movement Science, 24*, 326–344.
- 635 Roca, A., Williams, A. M., & Ford, P. R. (2014). Capturing and testing perceptual-cognitive  
636 expertise: A comparison of stationary and movement response methods. *Behavior*  
637 *Research Methods, 46*, 173–177.
- 638 Smallman, H. S., St. John, M., Oonk, H. M., & Cowen, M. B. (2001). Information availability in  
639 2D and 3D displays. *IEEE Computer Graphics and Applications, 21*, 51–57.
- 640 Starkes, J. L., & Lindley, S. (1994). Can we hasten expertise by video simulations? *Quest, 46*,  
641 211–222.
- 642 St. John, M., Cowen, M. B., Smallman, H. S., & Oonk, H. M. (2001). The Use of 2D and 3D  
643 displays for shape-understanding versus relative-position tasks. *Human Factors: The*  
644 *Journal of the Human Factors and Ergonomics Society, 43*, 79–98.
- 645 Stoffregen, T., Bardy, B., Smart, L., & Pagulayan, R. (2003). On the nature and evaluation of  
646 fidelity in virtual environments. In L. J. Hettinger & M. W. Haas (Eds.), *Virtual and*

647            *adaptive environments: Applications, implications, and human performance issues*

648            (pp. 111–128). Mahwah, NJ: Erlbaum.

649    Travassos, B., Araújo, D., Davids, K., O'Hara, K., Leitaó, J., & Cortinhas, A. (2013). Expertise

650            effects on decision-making in sport are constrained by requisite response

651            behaviours—A meta-analysis. *Psychology of Sport and Exercise, 14*, 211–219.

652

653

654    Figure 1

655