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1 Reading the Future from Body Movements –

2 Anticipation in Handball

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Abstract

In speed-based sports that require fast reactions, the most accurate predictions are made once the players have seen the ball trajectory. However, waiting for the ball trajectory does not leave enough time for appropriate reactions. Expert athletes use kinematic information which they extract from the opponent's movements to anticipate the ball trajectory. Temporal occlusion, where only a part of the full movement sequence is presented, has often been used to research anticipation in sports. Unlike many previous studies, we chose occlusion points in video-stimuli of penalty shooting in handball based on the domain-specific analysis of movement sequences. Instead of relying on randomly chosen occlusion points, each time point in our study revealed a specific chunk of information about the direction of the ball. The multivariate analysis showed that handball goalkeepers were not only more accurate and faster than novices overall when predicting where the ball will end up, but that experts and novices also made their decisions based on different kinds of movement sequences. These findings underline the importance of kinematic knowledge for anticipation, but they also demonstrate the significance of carefully chosen occlusion points.

Key words: *expertise, anticipation, temporal occlusion, multilevel modelling, handball*

38

Introduction

39 The importance of sport in our society can be measured not only by the amount of
40 material resources expended on it and the income made by it (Gratton, Shibli & Coleman, 2006;
41 Gratton, Dobson, Shibli, Gratton & Henry, 2001; Gratton, Dobson & Shibli, 2000; Gratton &
42 Taylor, 2000), but also by the amount of time and effort that people invest in it (Taks, Renson &
43 Vanreusel, 1994; Wall & Côté, 2007; De Grazia, 1964). It should not be surprising that people
44 have been fascinated by, and have tried to understand, what underpins the seemingly
45 supernatural powers of elite sport practitioners such as LeBron James in basketball, Yuzuru
46 Hanyu in figure skating or Thierry Omeyer in handball (for other topics researched within the
47 field of sport expertise, see Baker & Farrow, 2015; and Janell & Hillman, 2003). Research on
48 sport expertise demonstrates that elite practitioners are not necessarily endowed with
49 extraordinary reflexes, which enable them to react quickly (Starkes & Deakin, 1984). Rather,
50 they rely on stored motor programs for recognizing the situation at hand and anticipating the
51 outcome of the current scenario (Schmidt, 1975; 1988; Wright & Jackson, 2007; Williams &
52 Jackson, 2019). Here we demonstrate this anticipatory skill in handball goalkeepers. We do so by
53 identifying the crucial movement sequences in handball, rather than relying on the common
54 technique of dividing the whole sequence into parts of equal length. Our results show that not
55 only can expert goalkeepers focus on the informative motor sequences early enough, but that the
56 information they use for anticipation is considerably different from that used by novices.

57 To illustrate the difficulty of the task that athletes face in speed-based sports, consider the
58 seven-meter shot (penalty shot) in handball. Seven-meter shots are frequent in handball (around
59 four per game, see Foretić, Uljević, & Prižmić, 2010) and they pit the shooter and the goalkeeper
60 against each other. The distance between them is usually around six meters, as the goalkeepers

61 can move closer to the shooter to reduce the angle of the shot. With the ball moving at a speed of
62 around 20 meters per second (Kornexl, 1970), goalkeepers have 300 to 360ms, not only to decide
63 on, but also to execute, the defensive movement. This is a daunting task because even the best
64 goalkeepers need at least 500ms to choose a reaction and carry it out (Kastner, Pollany &
65 Sobotka, 1978; Sahre, 1986). Even if we assume that the goalkeepers have to choose between
66 only four possible directions of the ball (e.g., upper right, upper left, lower right, and lower left),
67 they would need between 300 and 450ms for their decision (Kastner et al., 1978, p. 294;
68 Kornexl, 1970, p. 224; Sahre, 1986, p. 80; Sinclair & Moyls, 1979, p. 60). One also needs to
69 account for the actual execution of the movement, which takes around 100-140ms. It is clear that
70 goalkeepers will have no chance of stopping the ball if they wait for it. Instead, goalkeepers have
71 to throw their body in the correct direction even before the shot has been made (Hatzl, 2000).

72 Goalkeepers in handball nevertheless manage to protect their goals using the same
73 anticipatory strategies as other athletes in speed-based sports, who normally do not have enough
74 time to react when the ball is already in the air (Loffing, Sölter, Hagemann & Strauss, 2015;
75 Bilalić, 2017; Loffing & Cañal-Bruland, 2017; Schorer, Panten, Neugebauer & Loffing, 2018).
76 Through focused training (Ericsson, Krampe & Tesch-Römer, 1993) and prolonged exposure in
77 the domain, they develop a system of perception that enables them to selectively perceive the
78 information (i.e. movements of the opponent's body) necessary for anticipation. They become
79 more familiar with the information and are thus able to group smaller pieces of information into
80 larger motor programs (Maxeiner, 1988). Larger chunks of information in turn allow athletes to
81 recognize incoming information more efficiently, essentially shortening the information
82 identification period and leaving more time for the appropriate reaction (Maxeiner, Pitsch &
83 Schwinn, 1996; Neumaier, 1983; 1985).

84 The ability to anticipate opponent movements is essential for success in sports in general,
85 especially for ball games, which are associated with high speeds of movements (Hagemann,
86 Tiejens & Strauss, 2007). Research on anticipation (Abernethy & Russel, 1987; Abernethy,
87 1991; Abernethy, Thomas & Thomas, 1993) has consistently found that experts exhibit vastly
88 superior anticipatory skills to novices across a wide range of sport domains (Williams, David &
89 Williams, 1999; Mann, Williams, Ward & Janelle, 2007; Williams and Jackson, 2019).
90 Researchers have usually employed temporal occlusion (Farrow, Abernethy & Jackson, 2005;
91 Farrow & Abernethy, 2007), a paradigm where videos of typical movement sequences are
92 stopped at different time points. The differing lengths of the videos manipulate the amount of
93 available kinetic information and enable the pinpointing of which phases of movement have the
94 greatest impact on the anticipation of actions (Abernethy, Farrow & Berry, 2003; Farrow &
95 Abernethy, 2007).

96 The common finding in these experiments is that, regardless of expertise level, the degree
97 of accuracy increases (and reaction time decreases) the later the cut in the video is made, and is
98 at its highest level once the ball leaves the player being watched - or in other words once the
99 participants are able to see the ball's trajectory and when the player actions can no longer affect
100 that trajectory (Farrow et al. 2005; Murphy, Jackson & Williams, 2018). This pattern of results is
101 consistent across a wide range of different sports and can be found in tennis (Jones & Miles,
102 1978; Ward, Williams & Bennet, 2002), hockey (Salamela & Fiorito, 1979), badminton
103 (Abernethy & Russel, 1987), football/soccer (Williams & Burwitz, 1993; Savelsbergh, Williams,
104 Kamp & Ward, 2002), squash (Howarth, Walsh, Abernethy & Snyder, 1984; Abernathy, Gill,
105 Parks & Packer, 2001), cricket (Penrose & Roach, 1995; Müller, Abernethy & Farrow, 2006),
106 basketball (Aglioti, Cesari, Romani & Urgesi, 2008; Wu, Zeng, Zhang, Wang, Wang, Tan &

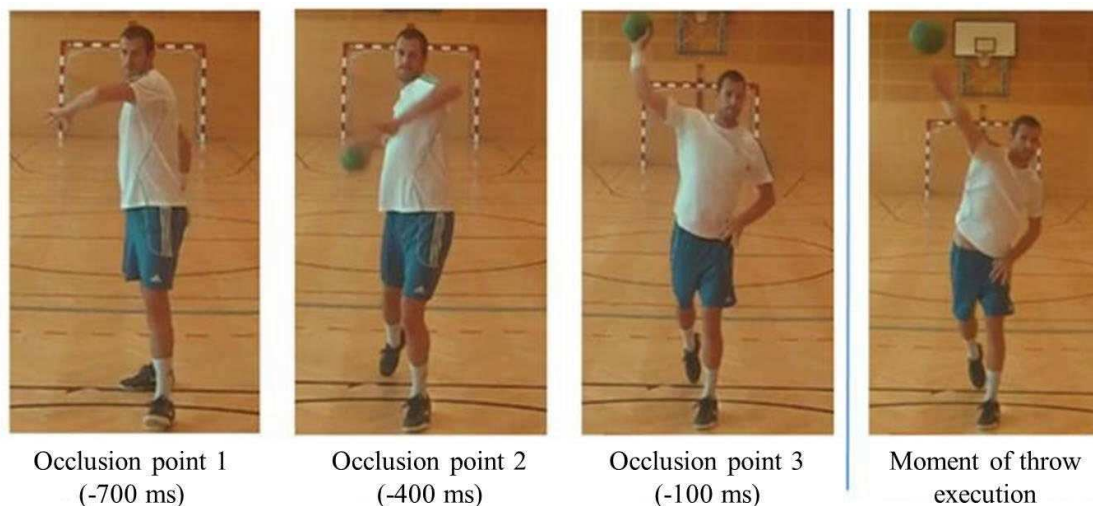
107 Zhang, 2013) and handball (Schorer, Baker, Fath & Jaitner, 2007; Schorer & Baker, 2009;
108 Gutierrez-Davila, Rojas, Ortega, Campos & Parrage, 2011; Abernethy, Schorer, Jackson &
109 Hagemann, 2012; Loffing & Hagemann, 2014; Alsharji, 2014).

110 However, the literature does not specify exact timings of occlusion points (i.e. the time
111 window when videos should be stopped). Some studies choose a critical event in the video and
112 then stop the video in equally long intervals before and after the event (e.g., Williams and
113 Burwitz, 1993). The number of occlusion points also varies greatly, starting from three and going
114 up to nine (e.g., Jones and Miles, 1978; Abernethy, Gill, Parks & Packer, 2001; Abreu,
115 Macaluso, Azevedo, Cesari, Urgesi, & Aglioti, 2012; Loffing & Hagemann, 2014). The
116 occlusion points vary not only between different domains, but also within the same sport and
117 even the same task (specific situation) in a sport (Farrow et al., 2005). All this may lead to
118 incongruent results, ranging from no differences between sequential time windows (throughout
119 the whole video) to clear differences between different occlusion points (e.g., Loffing &
120 Hagemann, 2014; Alsharji, 2014; Jackson, Warren & Abernathy, 2006; Abernathy, 1990).

121 Here we adopt a strategy of choosing the essential phases of executed movement and
122 dividing the video into clips connecting those phases (e.g., Loffing et al., 2014; Müller et al.,
123 2006). We use Hatzl's analysis (2000) of relevant body movements in handball, which found that
124 the crucial factors are: 1) the direction of the ball and ball-carrying hand in the last stage of the
125 throwing phase; 2) rotation of the hip and upper body around its longitudinal axis; 3) how far the
126 ball is from the body (to the side) and 4) relative shoulder width as seen from the goalkeeper's
127 perspective. These findings have been confirmed by using occlusion techniques (see below), eye-
128 movement recordings and statistical analysis of variations in handball shots and their importance
129 to differentiation of shot direction (Alhosseini, Safavi & Namazi, 2015; Loffing & Hagemann,

130 2014; Rivilla-García et al., 2013; Bourne, Bennet, Hayes & Williams, 2011). More specifically,
 131 Hatzl empirically concluded that the most informative period, when the anticipation most likely
 132 happens, was between the defined turning point of the throwing motion (first body rotation) and
 133 the time when the ball-carrying hand and the head of the thrower make their last turns.

134 Our occlusion points closely follow Hatzl's analysis (2000) of relevant body movements
 135 but we also keep the length between the occlusion periods constant. In this way, we ensured that
 136 each clip contained more information relevant for anticipation than its predecessor. The first
 137 occlusion point (see Figure 1) showed the beginning of the shooting and contained almost no
 138 relevant information; while the second and third occlusion points contained additional 300ms
 139 each, containing information pointed out as relevant in Hatzl's analysis (2000) for anticipation in
 140 handball (see Method for in-depth description).



141 Figure 1. *Sequence of the movement and occlusion points. The first occlusion point (far left*
 142 *panel) happens 700ms before the ball is released and contains no relevant information for anticipation.*
 143 *The second occlusion point (mid left panel), 400ms before the ball release, contains the important*
 144 *information about the rotation of the hip and upper body. The third and final occlusion point (mid right*
 145 *panel), just 100ms before the ball release, in addition to the previous information, entails the ball-*

168 have seen them before) but had never played organized handball¹. All participants signed a
169 written consent and the local ethics committee in Klagenfurt approved the study.

170 Our sample is similar in size to those of other studies researching anticipation in
171 handball: $N = 20$ in Alsharji (2014), $N = 37$ (14 experts and 23 non-experts) in Loffing &
172 Hagemann (2014), and $N = 10$ in Rivilla-García et al. (2013). Since Loffing & Hagemann used the
173 most similar research method to the one we used, we relied on that study when conducting power
174 analysis. In the study, effect size for the main effect of expertise (experts versus non-experts) is
175 $\eta_p^2 = .40$ ($F = 23.39$, $p < .001$) and for the main effect of temporal occlusion (5 time points) is $\eta_p^2 =$
176 $.42$ ($F = 25.4$, $p < .001$). Interaction between the two effects was not significant ($p = .39$);
177 however, polynomial contrasts revealed a linear trend (of accuracy improving with later temporal
178 occlusion) with effect size $\eta_p^2 = .71$ ($F = 83.81$; $p < .001$). Both main effects are large enough to
179 detect even with fewer participants (8 participants per group for the conventional 0.80 power; 12
180 for 0.95 power) for within factor analysis; however, effect sizes are not quite large enough to
181 detect for between factor analysis (15 participants per group for the conventional 0.80 power; 24
182 for 0.95 power). There are no studies that could be used to estimate the effect size for the
183 interaction between expertise and time occlusion (e.g., Alsharji study uses only a group of
184 experts, while other studies use a different approach to research). Therefore, in order to ensure
185 adequate statistical power, we have predefined time windows (where we made cuts) based on
186 previous studies, making them more relevant to the research question. We also used linear
187 mixed-effect regression, which takes into account all individual stimuli and therefore improves
188 overall power of the design (van Rij et al., 2018).

189

1 These participants are essentially beginners, but we refer to them as novices in this paper in accordance with the usual practice in this kind of research.

190 **Stimuli and design**

191 Appendix A provides detailed information about the stimulus creation. A professional
192 handball player was filmed performing penalty shots, with the task to shoot at one of the four
193 corners of the goal. The camera was centered a meter in front of the middle of the goal, making
194 the distance between the shooter and camera 6m. The camera was set at 180cm height with
195 angular viewpoint between the shooter and camera (goalkeeper point of view) being $17^{\circ} 59'$. In
196 the end, we used 60 videos, out of 200 filmed. There were 15 shots going top left, 15 going top
197 right, 15 going bottom left, and 15 going bottom right. All 60 videos were cut into three different
198 time points (occlusion points one, two, and three), which resulted in 180 videos that were used as
199 stimuli. The videos were filmed and cut in accordance with Hatzl's analysis (2000), so that each
200 clip captures relevant kinetic information. The length between the occlusion periods was kept
201 constant to ensure that each clip contained more information relevant for anticipation than its
202 predecessor. The videos were chosen in collaboration with a professional handball goalkeeper,
203 following these criteria: 1) no hesitation when executing the shot; 2) no tricks/fakes; 3) no shots
204 that deviate (in the slightest) from the targets (four corners of the goal); 4) must include clear
205 movements distinguished by Hatzl (2000) as relevant (if the movement was blurry or unclear the
206 video wasn't included). Upon choosing and cutting the videos, another Australian Handball
207 Bundesliga (1st league) player checked the stimuli and validated our selection. The analysis of
208 individual videos demonstrated that there was little variation across the chosen videos as
209 individual participants responded (RT and accuracy) similarly to all 60 videos (see Results and
210 Appendix C).

211 The first occlusion point showed the very beginning of the shooting sequence (see Figure
212 1) and the video lasted around² 400ms. The ball cannot be seen, and the player's body is turned
213 sideways, blocking the view of his ball-throwing arm, therefore containing almost no relevant
214 information. The videos cut at the second occlusion point contained both the movement shown in
215 the first video and another consecutive movement (see Figure 1). They lasted around 800ms.
216 Now, the ball can be seen, as well as the ball-throwing hand, and the direction of the head and
217 body have changed and are facing the camera more. This group of videos provides information
218 about hip and upper body rotation, as well as the distance of the ball from the body, that Hatzl
219 (2000) identified as relevant for anticipation. Finally, the third group of videos consisted of the
220 movement seen in the first two groups and the finishing movement of execution (see Figure 1).
221 However, the videos were stopped before the ball leaves the player's hand, so that the ball
222 trajectory cannot be seen and used to make predictions. In these videos, further body rotation
223 towards the camera is shown, the ball-throwing hand can be fully seen, and the position of the
224 shooter's right leg and his head direction can be used to make predictions. This this group of
225 videos additionally contained information about the ball-carrying hand and the shoulder width
226 during the last stage of the throwing phase deemed as relevant for anticipation (Hatzl, 2000).
227 Total duration of the videos in this group was around 970ms. The start time of (all of) the videos
228 relative to the ball release point was around 1100ms.

229

230

231

² Video clips, for the same time windows, somewhat varied in length (25-30ms) in order to ensure that they included complete movement sequence deemed relevant for anticipation.

232 Procedure

233 We explained to all participants that they were going to see the videos of seven-meter
234 shots from the goalkeeper's point of view, and that their task was to try to predict in which
235 corner of the goal the ball would end up going. They were seated, in a comfortable posture,
236 watching the videos on a 15-inch HD laptop screen (distance between participants and the screen
237 was 70cm with height of shooter image of 8cm, making angular viewpoint between the shooter
238 on screen and a participant $6^{\circ} 32'$; with angular viewpoint between actual shooter and camera
239 (goalkeeper point of view) $17^{\circ} 59'$). We used OpenSesame, version 2.9.7, for presenting the
240 stimuli (Mathôt, Schreij & Theeuwes, 2012). In order to ensure optimum/equal gaze direction,
241 the participants were shown a fixation dot before trial presentation, on which they were to focus
242 their gaze. The video stimuli were then presented at 30fps, after which participants were asked to
243 make a decision regarding where the ball would go by pressing one of the buttons on the
244 keyboard (Q, P, X, or M). The buttons were assigned so that they visually represented each
245 corner of the goal (from the goalkeeper's perspective), hence making it easier for participants to
246 make predictions.

247 The participants were first shown 13 practice videos (different from the ones used in the
248 main part of the experiment). They were given feedback on the correctness of their answers and
249 they were allowed to ask questions or to request additional explanations at this point. After they
250 had finished practicing and it was made sure that they understood their task, the main part of the
251 experiment commenced.

252 The participants were shown all 180 videos in randomized order. They were asked to
253 make a decision as quickly as possible regarding the final placement of the ball in the goal. Upon

254 finishing, they were thanked and debriefed. If they requested it, detailed feedback regarding their
255 performance was sent to them via email. The whole procedure lasted about 45 minutes.

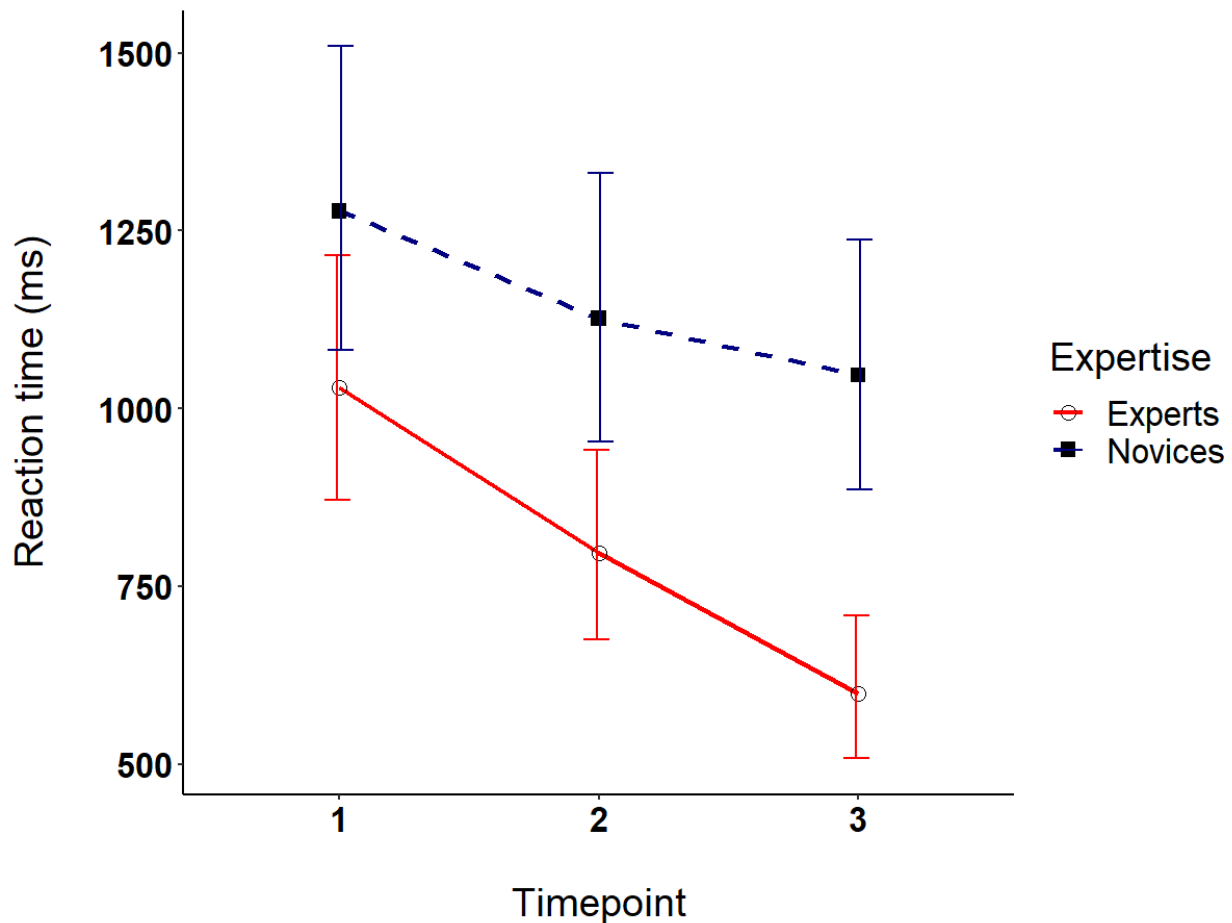
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Results

258 Reaction Time

259 The reaction results (Figure 2) show that experts were getting faster to the same extent in
260 their decisions as more information is revealed (later occlusion points). In contrast, novices were
261 faster in deciding as more information was revealed, but their improvements were not constant.



262

263 Figure 2. Reaction time of experts and novices at three occlusion points. Error bars represent one standard
264 error (SE).

265 To statistically check the effect of temporal occlusion on the speed of the reaction when
266 predicting the outcome of the penalty shot in handball (and later the accuracy), we used linear
267 mixed-effect regression in R statistical environment (Wood, 2017; R core team, 2018 – for the
268 sake of completeness, we provide the classical ANOVA table in Appendix B). The main idea of
269 this method is to control additional sources of variability in the dependent variable, which are not
270 influenced by the manipulated factors (fixed effects). In the case of experimental designs with
271 repeated measurements for individual participants, intra-individual variations are often of lesser
272 interest to the researchers. Because of these additional variations, practitioners use group
273 averages as an input for the general linear model (i.e. ANOVA). The linear mixed-effect analysis
274 handles responses from individual trials by treating the grouping factors as sources of additional
275 variability (random-effect structure). Contrary to the ANOVA that uses average data (per item or
276 per participant for each condition), mixed-effect models use individual (raw) data as input to
277 calculate regression coefficients. The mixed-effect model utilizes individual reaction
278 times/accuracy rates for all participants in the experiment across all conditions. A statistical
279 feature that allows such modelling is a specification of a random structure, that is, the inclusion
280 of factors or experimental information that can influence the results but are not manipulated in
281 the experiment. The random effects are represented by one parameter: standard deviation of the
282 particular grouping factor. When treating individual participants as random effects, the estimates
283 of the random structure added to the fixed effects (manipulated factors) provide an estimate of
284 the participant's performance. These estimates constitute a compromise between the overall
285 mean of performance for all players and the individual data of the participants. This way, the
286 outliers and participants with missing data are drawn towards the general mean of performance
287 (van Rij, Vaci, Wurm & Feldman, 2018). The linear mixed-effect modelling proves extremely

288 useful when modelling repeated measurements data where the variability of the dependent
289 variable comes from multiple different sources, as well as in the case of the data with non-
290 Gaussian distribution and missing data. The standard estimation of the parameters in the linear
291 mixed-effect analysis is a comparison between the combinations of the factors used in the
292 experiment, which is parallel to the post-hoc comparison in the ANOVA analysis. Similarly, as
293 with factorial models, we can calculate omnibus tests and investigate the overall significance of
294 the factors in the model.

295 In the case of this study, the reaction time was used as the dependent variable in the linear
296 mixed-effect model. To approximate the normal distribution, we log transformed the raw
297 reaction times (see Baayen & Milin, 2010). After we estimate the model, the log-transformed
298 values can be easily reverted to the original reaction time values by applying the exponential
299 transformation. In the fixed-effect structure, we included the information about expertise level
300 (experts versus novices) and temporal occlusion points (1st, 2nd, and 3rd), while participants and
301 individual items were included as random-effect structure. The experts and first occlusion point
302 were treated as referential levels in analysis: that is, novices and the second and third occlusion
303 points were compared to them.

304 Table 1 summarizes the results of the analysis. The linear mixed-effect analysis utilizes
305 standard dummy coding of categorical predictors to estimate the regression coefficients. In
306 particular, one level is dropped from each factor and serves as a referential level with which all
307 other levels and their combinations are compared. The intercept in this type of analysis
308 represents the predicted value of dependent variable (reaction time) for a combination of baseline
309 categories, that is, excluded levels (Expertise: experts, Occlusion point: 1st time point). All other
310 factor levels and their combinations (shown in the Table 1) are consequently compared with the

311 baseline combination of levels. Therefore, the results show that there were no overall significant
 312 differences between experts and novices at the first occlusion point ($b = 0.21, t = 0.91, p = .35$).
 313 Experts reacted more quickly at the 2nd ($b = -0.25, t = -8.79, p < .001$) and 3rd occlusion point (b
 314 $= -0.53, t = -18.63, p < 0.001$) than on the 1st time point. Finally, this difference between 1st and
 315 2nd time point was smaller for novices than for experts ($b = 0.12, t = 3.14, p < .01$), as well as, the
 316 difference between 1st and 3rd time point ($b = .34, t = 8.30, p < .001$). To be able to estimate
 317 changes from 2nd to 3rd occlusion point, we set the 2nd occlusion point as reference level and re-
 318 run the model. As expected, the difference between 2nd and 3rd was significant for experts ($b = -$
 319 $0.12, t = -3.14, p < 0.01$), while still weaker for novices than for experts ($b = 0.21, t = 5.17, p <$
 320 0.001). The model with these two factors and by-participant and by-item random structure
 321 explained 57% of the variance in reaction time. The variance for intercept adjustment was
 322 estimated stronger between participants (variance = 0.27 log RT) in comparison to the variance
 323 between items/videos (variance = 0.01 log RT). In other words, different participants respond
 324 consistently slower or faster, while different stimuli elicit equally fast responses. The Appendix
 325 C illustrates random adjustments for each participant and each item in the reaction time (see
 326 Figure C1) and accuracy analysis (see Figure C2).

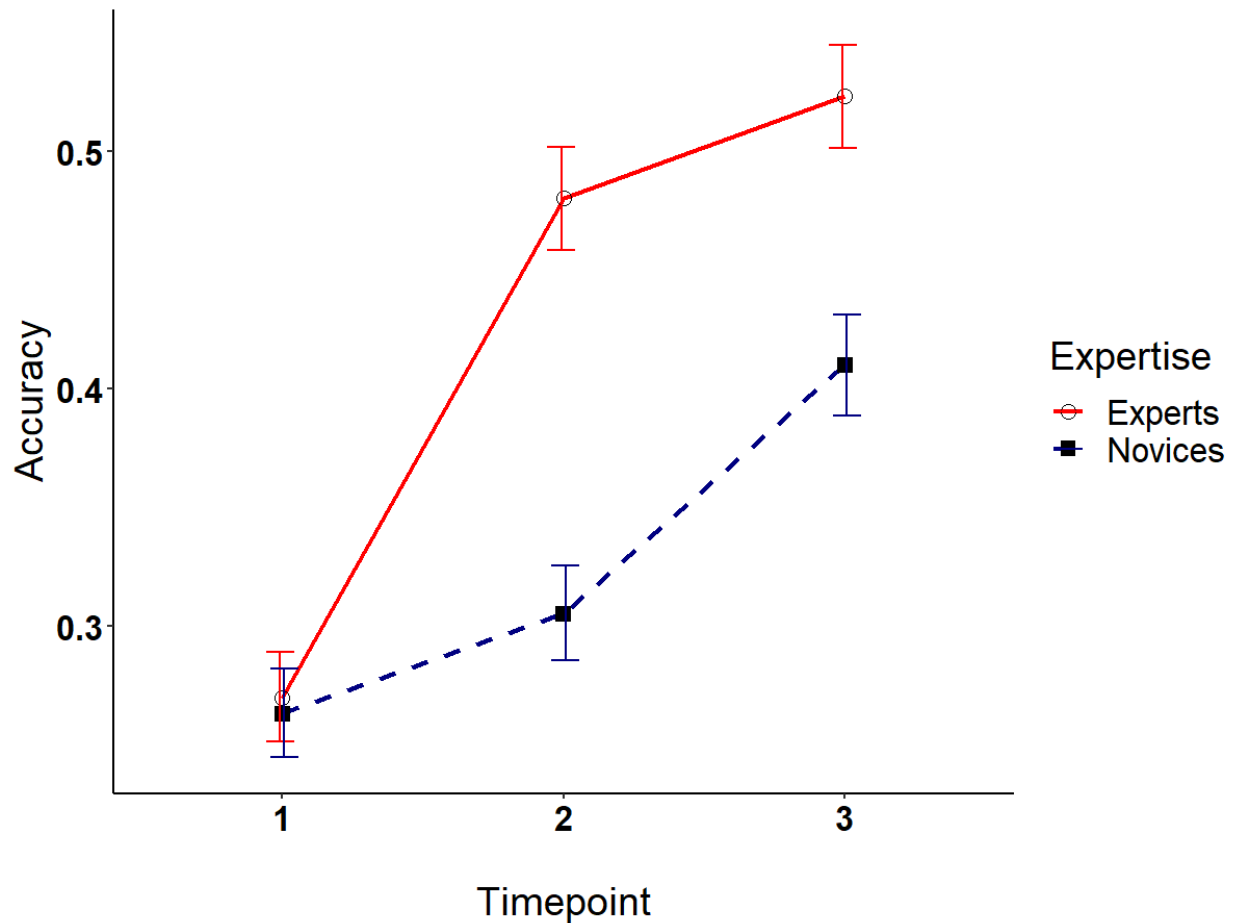
327 Table 1. The results of the linear mixed-effect model on the reaction time.

Parametric coefficients:				
	Estimate	Std. Error	t value	Pr(> t)
Intercept	6.93	0.16	41.46	< 2e-16
Expertise(novices)	0.21	0.23	0.917	.358
Time(2)	-0.25	0.02	-8.797	< 2e-16
Time(3)	-0.53	0.02	-18.63	< 2e-16
Expertise(novices): Time(2)	0.12	0.04	3.144	0.00168
Expertise(novices): Time(3)	0.34	0.04	8.306	< 2e-16
Approximate significance of smooth terms:				
	Edf	Ref.edf	F	p-value
s(Subjects)	17.91	18	203.240	< 2e-16
S(Items)	92.58	179	1.073	1.48e-14

328

329 **Accuracy**

330 The experts were unsurprisingly more accurate than novices (see Figure 3), but they
 331 already achieved respectable accuracy levels by the 2nd occlusion point (keep in mind that chance
 332 level is 0.25). The additional information available in the third occlusion point improved experts'
 333 performance, but it had more effect on novices who only here could with some success predict
 334 where the ball will land.



335

336 Figure 3. Accuracy (proportion) of experts and novices at the three occlusion points.

337

338 In the case of the accuracy, we used logistic mixed-effect analysis with the same fixed and
 339 random-effect structure as in the analysis of reaction time. Table 2 presents overall significance

340 of factors and their interactions. Similar to the mixed-effect model on reaction time, the model
341 built on accuracy also uses individual data (non-averaged measures), while random effect
342 structure adjusts the estimates from the model by specifying the repeated (clustered)
343 measurements. We specified that dependent variable is following binomial distribution forcing
344 model to calculate regression coefficients in the log-odds space. In other words, we did not
345 separately transform the input to the model, e.g. calculate probability or frequencies per
346 condition, but used the outcomes in their natural format.

347 Similar to the reaction time analysis, results show significant interaction between
348 temporal occlusion point and expertise level. The experts and novices do not differ on the first
349 occlusion point ($b = -0.03$, $z = -.025$, $p = .80$). Experts extract more information at the second (b
350 $= 0.90$, $z = 7.28$, $p = < .001$) and third occlusion point ($b = 1.07$, $z = 8.65$, $p = <.001$) in
351 comparison to the first occlusion point, that is, their accuracy increases when answering on the
352 experimental task. As with the reaction time, the extraction of information from 1st to the 2nd ($b =$
353 -0.69 , $z = -3.90$, $p < .001$), as well as, from the 1st to the 3rd ($b = -0.41$, $z = -2.35$, $p = < .05$) time
354 point is much better utilized by experts than novices. They are generally more accurate and are
355 superior in reading the movement to novices already at the second occlusion point.

356 We also investigated changes of accuracy in anticipation from 2nd to the 3rd occlusion
357 point between experts and novices by changing the referential level of time occlusion factor. In
358 contrast to the results on the reaction time, results show that experts do not benefit from more
359 information between 2nd to 3rd time point ($b = 0.16$, $z = 1.45$, $p = .14$), while novices tend to
360 improve more but the differences did not quite reach the significance level ($b = 0.28$, $z = 1.67$, p
361 $= .09$). The model with these two factors and by-participant and by-item random structure
362 explained 5% of the variance in accuracy. Unlike the reaction time analysis, the estimated

363 variance of random intercepts was higher for items/videos (variance = 0.14) than for subjects
 364 (variance = 0.004). The weak contributions of the random structures indicate that all participants
 365 respond on task with similar baseline accuracy, while all stimuli elicit similarly accurate
 366 responses (see Figure C2 in Appendix). Contrary to this, most of the differences in the accuracy
 367 are observed due to the manipulated factors.

368

369 Table 2. *The results of the logistic mixed-effect model on the accuracy.*

Parametric coefficients:				
	Estimate	Std. Error	z-value	Pr(> t)
Intercept	0.98	0.09	-10.04	< 2e-16
Expertise(novices)	-0.03	0.13	-0.251	.801
Time(2)	0.90	0.12	7.286	< 2e-16
Time(3)	1.07	0.12	8.656	< 2e-16
Expertise(novices): Time(2)	-0.69	0.17	-3.908	9.31e-05
Expertise(novices): Time(3)	-0.41	0.17	-2.359	0.0183
Approximate significance of smooth terms:				
	Edf	Ref.edf	F	p-value
s(Subjects)	3.68	18	4.587	0.213
S(Items)	43.63	179	57.33	0.003

370

371

Discussion

372 In order to successfully parry a penalty shot in handball, goalkeepers need to anticipate
 373 the final destination of the ball even before the ball leaves the thrower's hand. Our results
 374 demonstrate well-developed anticipatory skills in handball goalkeepers. Even 400ms before they
 375 saw the ball trajectory (occlusion point 2), experts could judge where the ball is going to go
 376 considerably above the chance. This ability is acquired, as novices, with far less experience, were
 377 consistently worse in anticipation. Both experts and novices could extract more useful kinetic
 378 information as the amount of information increased in the subsequent occlusion points (see also,
 379 Farrow et al., 2005; Maxeiner et. al., 1996). However, experts were able to identify and utilize

380 the relevant information better and more rapidly than novices (see also, Gredin, Bishop, Tucker
381 & Williams, 2018; Maxeiner, 1988).

382

383 **Importance of meaningful occlusion points in anticipation research**

384 The first occlusion point, which ends 700 ms before the ball is thrown, has no relevant
385 information (Hatzl, 2000). The accuracy performance is therefore around the chance level as
386 even experts could not rely on their knowledge. The second occlusion point contained the
387 information about rotation of the hips and upper body, both important indicators of anticipation
388 (Hatzl, 2000). This resulted in significantly better performance in both groups when compared to
389 the first one. The third and final occlusion point contained additional important information for
390 anticipation about the direction of the ball-carrying hand, which improved the anticipation
391 additionally in both groups.

392 Although both groups improved their performance with additional information, there
393 were important differences. The anticipatory increase for experts was highest in the second
394 occlusion point (from 26% to 50%). In contrast, novices showed a particular increase in
395 performance in the third and final occlusion point (from 30% on the second occlusion point to
396 42% on the third). The differing pattern suggests that the two groups use different kinematic
397 clues for their performance. Experts can base their decision on the information about the rotation
398 of the hips and upper body, which is present in the second occlusion point (Neumaier, 1983;
399 1985). The additional information about the shooting hand improves the experts' anticipation
400 only to a certain extent. In contrast, novices benefitted considerably from the information about
401 the ball-carrying hand.

402 These results underline a large body of research that demonstrates experts' ability to
403 make informed decision about an outcome before it actually happens. Expert in all sport domains
404 extract the necessary information for prediction from the body movements that precede the
405 outcome (Gredin et al (2018), Loffing, Cañal-Bruland & Hagemann (2014), Willams and
406 Burwitz (1993) and Penrose and Roach (1995) Bideau et al. (2004) and Vignais et al. (2009).
407 Our study goes beyond the previous results because it pinpoints the crucial time for anticipation
408 as well as the exact kinetic information on which experts' decisions are based. The analysis that
409 includes the identification of meaningful occlusion points may go a long way toward explaining
410 inconsistent findings in previous research. For example, Loffing and Hagemann (2014), while
411 examining anticipation ability in seven-meter shots, chose five different time points before the
412 ball was released. However, even though the duration of the whole video was 3 seconds, chosen
413 time cuts were very close to each other: videos were occluded either at the moment of ball
414 release (t_0) or at 4 earlier time cuts, between which were 40ms of time difference (the earliest
415 time cut, t_4 happens 160ms before the ball release). Therefore, all of the stimuli included very
416 similar kinetic information, while additional 40-160ms (depending on the time cut) at the end of
417 stimuli did not include information relevant for anticipation in handball (Hatzl, 2000). This made
418 it hard for experts to pick up and respond to additional information carried in different time
419 windows. Consequently, there were no differences between consecutive time periods.

420 Similarly, Alsharji (2014) also defined five time windows in his analysis of the ability to
421 anticipate seven-meter shots in handball. However, those time windows included two from when
422 the ball was already released and three which included movement before the release. As
423 mentioned before, reacting only after the ball has been released will not result in a successful
424 save (Schorer, 2006) as it does not leave enough time for goalkeepers to make an informed

425 decision, choose and execute an adequate motor response program. Therefore, information from
426 the last two occlusion points in Alsharji's study (2014) is not informative. Even though the first
427 three occlusion points contained pre-throw movements, the starting point of the sequence was
428 chosen to be in the middle of the movement execution (when the body was already rotated and
429 one could see the thrower's hand clearly). This ignores the analysis of relevant movements for
430 anticipation (e.g Hatzl, 2000) and has consequently resulted in no significant difference between
431 consecutive time windows.

432

433 **Reaction time in anticipation research**

434 Our results also emphasize the importance of complementing the measures of accuracy
435 with the measure of reaction time in studies on anticipatory skill (for similar analysis in different
436 sport domains, see Mann, Williams, Ward & Janelle, 2007; Farrow et al. 2005). The reaction
437 time data underline the anticipation ability of expert goalkeepers in handball as we asked the
438 participant to react as quickly as possible, simulating the actual goalkeeping reaction. Only at the
439 last occlusion point (Figure 2), when they have 100ms before the ball is released, do expert
440 goalkeepers no longer have enough time to decide and execute the defensive motor program.
441 This scenario is based on Schorer's analysis (2006), which found that: a) the ball travels for
442 about 300-360 ms before it reaches the goalkeeper; b) the reaction time of goalkeepers for
443 initiating movement is between 200-250 ms; c) the time it takes for one step defensive
444 movement is between 100-180 ms. According to this analysis, the goalkeepers will have between
445 400 and 460ms (time from 3rd occlusion point to ball release + time to reach the goalkeeper) to
446 decide on and execute the motor movement. Our experts needed on average about 600ms for
447 their response, but one needs to consider that the actual button press also takes around 200-

448 300ms (Teichner, 1954; Klemmer, 1956; Niemi & Näätänen, 1981; Helm, Reiser & Munzert,
449 2016; Przednowek, Sliz, Lenik, Dziadek, Cieszkowski, Lenik, Kopeć, Wardak & Przednowek,
450 2019). Subtracting the time for simple reaction would leave experts with around 300-400ms
451 decision time. Since one also needs to execute the defensive movement (100-180 ms), it becomes
452 clear that successfully parrying the penalty shot may become rather difficult.

453 However, at all other time points, experts will have plenty of time to parry the shot. In
454 order to make a save, the participants' reaction time would have to be between 1000-110ms in
455 the first occlusion point and 700-800ms in the second one. Taking into account the
456 aforementioned analysis by Schorer (2006), experts were able to react in good time in the first
457 two occlusion points, and possibly in the third one too. On the other hand, novices' reactions are
458 too slow for successful defence, even when we account for the simple reaction time included in
459 their total reaction time. They do get significantly faster with increase in information, but the
460 time window for successful reaction is shorter in subsequent occlusion points. This provides
461 ecological validation for the results. Although novices may be able to predict the outcome of
462 penalty shots after a certain amount of information (occlusion points two and three), their
463 decisions are not fast enough.

464 The combination of accuracy and reaction time can also be used to determine the
465 ecological validity of the study. For example, in the German handball Bundesliga, arguably the
466 strongest handball league in the world, goalkeepers save on average about 20% of seven-meter
467 penalties³. Other research also indicates that the efficiency of the goalkeepers is around 20% on

³ <https://www.dkb-handball-bundesliga.de/en/dkb-hbl/statistics/statistics/statistics/season-16-17/season-statistics/goalkeeper/>

468 penalty shots in local competition (Greek premier handball leagues – Hatzimanouil, Giatsis,
469 Kepesidou, Kanioglou & Loizos, 2017), World Cup (Hansen, Sanz-Lopez, Whiteley, Popovic,
470 Ahmed & Cardinale, 2017), or over a long period of time at the top level (Espina-Agulló, Pérez-
471 Turpin, Jiménez-Olmedo, Penichet-Tomás & Pueo 2016). This may appear to be a low success
472 rate, given that our goalkeepers, who are arguably not as good as the best Bundesliga
473 professional goalkeepers, manage one in two successful reactions already at occlusion two point
474 (see Figure 2). One needs to consider, however, the fact that in the real game the players are able
475 to throw the ball to more than four predefined spots. The goalkeeping decisions are also made
476 more difficult by the use of deception techniques such as fake throws or adding different
477 amounts of spin to the throw. Both these factors will decrease the success of anticipation.

478

479 **Future directions and conclusion**

480 Besides using meaningful occlusion points and the combination of the accuracy and
481 reaction time measures, our study featured, for the first time in research on anticipation skill (to
482 our knowledge), multilevel analysis. Analyses that make use of all individual trials instead of
483 manipulating averages of individual participants are gaining considerable popularity in
484 psychological research (Pinheiro & Bates, 2000; Gelman & Hill, 2007; Baayen et al., 2008). In
485 comparison to classical analysis, multilevel models perform better in the case of unbalanced
486 designs, non-normality in dependent variable, and repeated measure covariates (Baayen, 2008;
487 Barr et al., 2013; Radanović & Vaci, 2013; van Rijn et al., 2018). In other words, these models
488 represent a more sensitive statistical tool at researchers' disposal. Our hope is that our study will
489 pave the way for the use of multilevel modelling in research on anticipation skill in sports; for

490 this reason, we provide access to the commented code used for the analysis of our data in the
491 online supplement.

492 Our results also point out a couple of future avenues worth exploring. We have identified
493 the rotation of the hips (occlusion point two) as the early kinetic information available to experts.
494 To confirm its importance for anticipation, one could employ eye movement recordings of
495 experts (Kurz, Hegele & Munzert, 2018; Kredel, Vater, Klostermann & Hossner, 2017).
496 Similarly, the spatial occlusion technique, where one occludes different body parts, may provide
497 a definitive answer regarding the role of this particular information (Dicks, Button, Davids,
498 Chow & Van der Kamp, 2017).

499 Given that, in the experimental conditions, participants' viewpoint of shooter is not only
500 two-dimensional (as it appears on screen) but is also less than half the retinal size of the real-life
501 image, the issue of ecological validity could be raised (Mann, Dicks, Cañal-Bruland R & van der
502 Kamp, 2013). Therefore, in future research, a more naturalistic approach may be the use of
503 liquid-crystal occluding goggles (Milgram, 1987) in the real simulations of the seven-meter
504 penalty. The goggles could be externally manipulated to block the vision at crucial moments,
505 thus simulating the occlusion paradigm in the real world. This technique, which has been
506 successfully used in other sports (Starkes, Edwards, Dissanayake & Dunn, 1995; Féry &
507 Crognier, 2003; Farrow & Abernethy; 2003), would allow goalkeepers to really execute the
508 defensive movement. This may be particularly relevant in this study because we noticed that
509 some experts participating in this study, upon seeing the stimuli, moved their hands reflexively
510 before pressing the button, as if they were actually defending their goal. This pattern of
511 behaviour, which was not noticed among novices, may have suppressed the reaction time. The
512 liquid plasma goggles would, among other things, also deal with this particular problem.

513 Our study demonstrates that kinetic knowledge is the essence of expertise in sport. It also
514 underlines the importance of the definition of meaningful occlusion points in the research on
515 anticipation. Only carefully chosen occlusion points allow insights into how different patterns of
516 movement impact expert ability to anticipate. The importance of this finding extends beyond the
517 laboratory, as only the findings based on meaningful occlusion points can serve as the basis for
518 the training of future experts. Our study identified the crucial occlusion points based on the
519 typical movement analysis (Hatzl, 2000) as well as the time reactions of experts (Schorer, 2006).
520 *Herewith we declare no conflict of interest.*

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Appendix A

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Stimuli creation procedure

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Videos used as stimuli in this study were recorded at the University Sport Institute (USI) in

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Alpen-Adria University of Klagenfurt (Austria). The process of making stimuli took two days.

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During the first day, we chose adequate camera settings for recording, as well as optimal lighting

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conditions. The ideal ball colour (blue) was chosen from a few different ones so that it was as

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distinguishable from the floor colour as possible. We examined the condition of the parquet so as

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to stay clear from possibly damaged parts, which could impact the way the ball bounces. Finally,

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the ideal hall temperature was chosen.

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Each of the four corners of the goal were taped (see Figure A1) to make it clearer to the

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handball player being filmed which parts of the goal he was supposed to target while shooting

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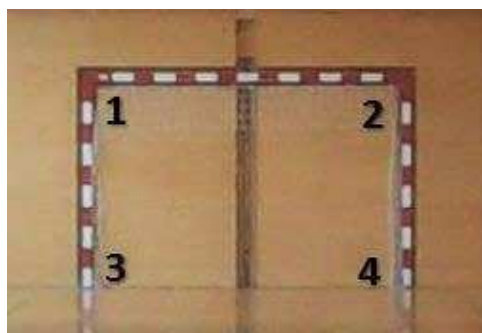
penalty shots (hence making the precision of shots as high as possible). All specificities in these

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setting were chosen in accordance with a professional handball goalkeeper's counsel. Once all

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preparations had been made, test filming was conducted with a professional handball goalkeeper.



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Figure A1. *Goal marks used in the study.*

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Based on the insights from trial filming on the first day, the optimal time window was

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chosen (4 hours) with the best possible conditions for filming. Also, upon viewing the test

784 material, we designed a detailed flow chart of how the process of filming was to be conducted. It
785 was decided that the order of where the seven-meter (penalty) shots were to be aimed was to be
786 randomized.

787 During the second day, we recorded the footage that was used in the experiment. We
788 used a GoPro Hero 4 camera for the filming itself. This was on a camera stand positioned at a
789 typical spot for a handball goalkeeper – in the very middle of the goal and about one meter in
790 front of it. The lenses of the camera were set at a height of 180cm. Precise orientation and
791 rotation of camera was carried out using a mobile phone application, GoPro RM, on a Samsung
792 Galaxy 3 Mini (the camera and phone were connected via Bluetooth). In addition to the
793 goalkeeper's opinion, another handball player's advice was taken into account while deciding the
794 best possible camera orientation for filming videos. Two hundred videos were recorded in this
795 setting.

796 In order to make the footage as ecologically valid as possible we recruited a professional
797 handball player with 20 years of experience. He was asked to shoot penalty shots as precisely as
798 possible (as if his team's victory was depending on the shots he was making). The order of where
799 the ball was to be shot was randomized. Targeted corners of the goal were visually signalled just
800 before each throw was conducted. This was done in order to ensure that the movement during the
801 seven-meter shots was as authentic as possible. There were no trick/fake throws – the shooter
802 was instructed to throw the ball as straight as possible to the assigned corner. The player made all
803 of the throws with his right hand.

804 Out of the 200 videos that were made (50 shots in each corner of the goal) we chose the
805 15 best ones per corner based on the precision of the shot, the clarity of the video, etc. Therefore,
806 a total of 60 videos were to be used for testing purposes.

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Appendix B

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Classical ANOVA analyses on reaction and accuracy

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Table B1. The results of ANOVA on the reaction time.

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Within Subjects Effects

	Sum of Squares	df	Mean Square	F	p	η^2_p
Occlusion	1.228	2	0.614	21.63	< .001	0.546
Occlusion * Group	0.692	2	0.346	12.19	< .001	0.404
Residual	1.022	36	0.028			

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Between Subjects Effects

	Sum of Squares	df	Mean Square	F	p	η^2_p
Group	2.898	1	2.898	3.765	0.068	0.173
Residual	13.856	18	0.770			

Note. Type III Sum of Squares

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Table B2. The results of ANOVA on the accuracy.

Within Subjects Effects

	Sum of Squares	df	Mean Square	F	p	η^2_p
Occlusion	0.471	2	0.235	102.11	< .001	0.850
Occlusion * Group	0.088	2	0.044	19.05	< .001	0.514
Residual	0.083	36	0.002			

816

Between Subjects Effects

	Sum of Squares	df	Mean Square	F	p	η^2_p
Group	0.173	1	0.173	31.93	< .001	0.639
Residual	0.098	18	0.005			

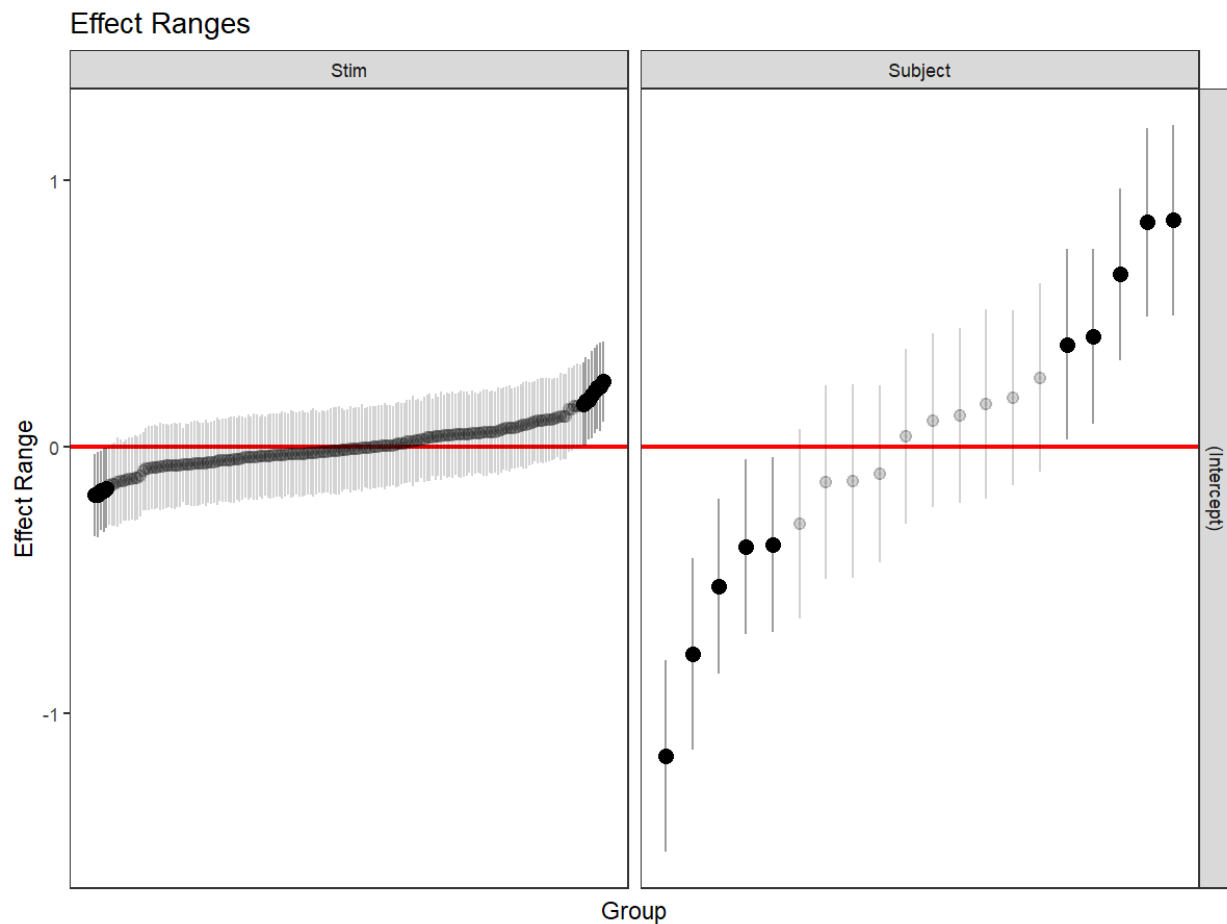
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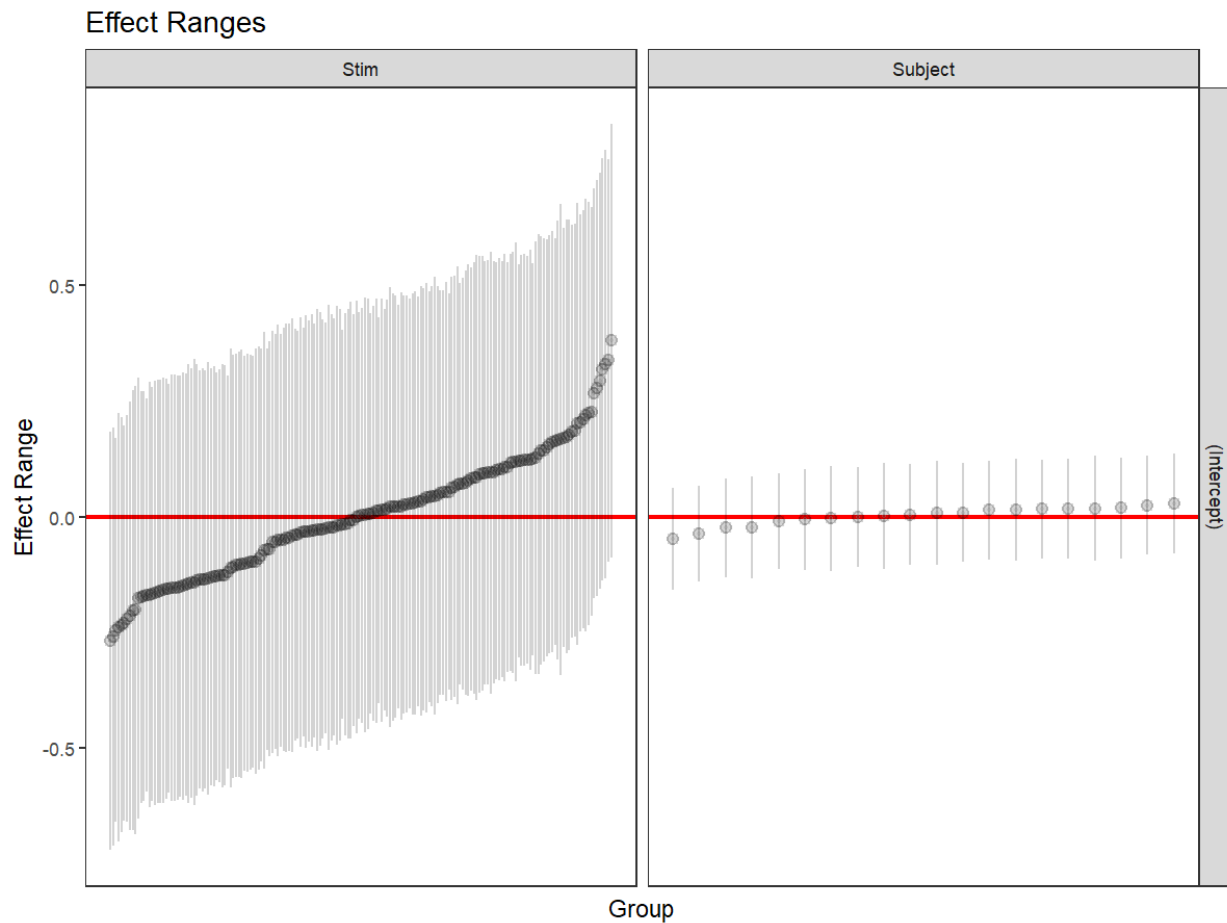
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Appendix C

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821 Figure C1. Random adjustments of the intercept in the case of reaction time analysis. Left:
 822 random adjustments of the intercept for stimuli (videos); Right: random adjustments of the
 823 intercept for participants in the experiment. Red line indicates global estimate of the intercept,
 824 while individual estimate illustrate how much is intercept adjusted for each level of the factor.



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827 Figure C2. Random adjustments of the intercept in the case of accuracy analysis. Left: random
 828 adjustments of the intercept for stimuli (videos); Right: random adjustments of the intercept for
 829 participants in the experiment. Red line indicates global estimate of the intercept, while
 830 individual estimate illustrate how much is intercept adjusted for each level of the factor. (Note
 831 that the range of y-axis here is much smaller than for RT.)

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