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Reading the Future from Body Movements – 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*

Introduction

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

To illustrate the difficulty of the task that athletes face in speed-based sports, consider the seven-meter shot (penalty shot) in handball. Seven-meter shots are frequent in handball (around four per game, see Foretić, Uljević, & Prižmić, 2010) and they pit the shooter and the goalkeeper against each other. The distance between them is usually around six meters, as the goalkeepers can move closer to the shooter to reduce the angle of the shot. With the ball moving at a speed of around 20 meters per second (Kornexl, 1970), goalkeepers have 300 to 360ms, not only to decide on, but also to execute, the defensive movement. This is a daunting task because even the best goalkeepers need at least 500ms to choose a reaction and carry it out (Kastner, Pollany & Sobotka, 1978; Sahre, 1986). Even if we assume that the goalkeepers have to choose between only four possible directions of the ball (e.g., upper right, upper left, lower right, and lower left), they would need between 300 and 450ms for their decision (Kastner et al., 1978, p. 294; Kornexl, 1970, p. 224; Sahre, 1986, p. 80; Sinclair & Moyls, 1979, p. 60). One also needs to account for the actual execution of the movement, which takes around 100-140ms. It is clear that goalkeepers will have no chance of stopping the ball if they wait for it. Instead, goalkeepers have to throw their body in the correct direction even before the shot has been made (Hatzl, 2000).

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

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

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

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

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

Here we adopt a strategy of choosing the essential phases of executed movement and dividing the video into clips connecting those phases (e.g., Loffing et al., 2014; Müller et al., 2006). We use Hatzl's analysis (2000) of relevant body movements in handball, which found that the crucial factors are: 1) the direction of the ball and ball-carrying hand in the last stage of the throwing phase; 2) rotation of the hip and upper body around its longitudinal axis; 3) how far the ball is from the body (to the side) and 4) relative shoulder width as seen from the goalkeeper's perspective. These findings have been confirmed by using occlusion techniques (see below), eye-movement recordings and statistical analysis of variations in handball shots and their importance to differentiation of shot direction (Alhosseini, Safavi & Namazi, 2015; Loffing & Hagemann, 2014; Rivilla-García et al., 2013; Bourne, Bennet, Hayes & Williams, 2011). More specifically, Hatzl empirically concluded that the most informative period, when the anticipation most likely happens, was between the defined turning point of the throwing motion (first body rotation) and the time when the ball-carrying hand and the head of the thrower make their last turns.

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

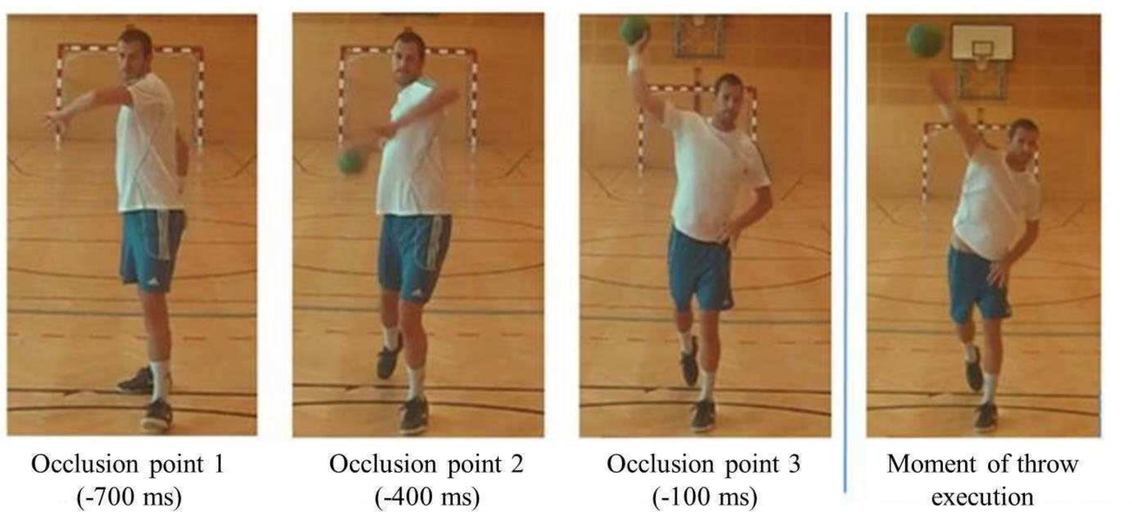

Figure 1. *Sequence of the movement and occlusion points. The first occlusion point (far left panel) happens 700ms before the ball is released and contains no relevant information for anticipation. The second occlusion point (mid left panel), 400ms before the ball release, contains the important information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

carrying hand and the shoulder width information. The last panel (far right) shows the moment when the ball leaves the shooter's hand. This part was not shown to the participants and is here for illustrative purposes.

Based on the previous studies (Farrow et al. 2005; Maxeiner, 1988; Maxeiner, Pitsch & Schwinn, 1996), we expect no significant difference between the expert and novice goalkeepers in the first occlusion point and performance around chance level, due to the fact that at this time point there is no relevant information. The second occlusion point was the crucial one because it contained the most relevant information for expert goalkeeper anticipation (Loffing & Hagemann, 2014). We expect clearly above chance performance in experts while novices' performance should be around chance. The final occlusion point provides more information, but given that this information is not crucial for experts, we do not expect a large increase in experts' performance from the second occlusion window. In contrast, this information may help novices to finally reach performance above chance level. We expect the same pattern of results with the reaction time. (Please note that we provide all the data, including the sample of stimuli, and the analysis reported in the manuscript – https://osf.io/4kn8f/.)

Method

Participants

Experts were 10 handball goalkeepers (Age M = 30.5, SD = 5.5 years, range 23-39, all male) who at the time of the study played in the top three Austrian leagues. They had on average 17 years of handball goalkeeping experience (SD = 3.8, range between 12 and 25 years). The group of novices consisted of 10 participants (Age M = 26.4, SD = 3.7, range 22-34, all male) who were familiar with the rules and dynamics of the game (including the seven-meter shots and have seen them before) but had never played organized handball[1]. All participants signed a written consent and the local ethics committee in Klagenfurt approved the study.

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

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.

Stimuli and design

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

The first occlusion point showed the very beginning of the shooting sequence (see Figure 1) and the video lasted around[2] 400ms. The ball cannot be seen, and the player's body is turned sideways, blocking the view of his ball-throwing arm, therefore containing almost no relevant information. The videos cut at the second occlusion point contained both the movement shown in the first video and another consecutive movement (see Figure 1). They lasted around 800ms. Now, the ball can be seen, as well as the ball-throwing hand, and the direction of the head and body have changed and are facing the camera more. This group of videos provides information about hip and upper body rotation, as well as the distance of the ball from the body, that Hatzl (2000) identified as relevant for anticipation. Finally, the third group of videos consisted of the movement seen in the first two groups and the finishing movement of execution (see Figure 1). However, the videos were stopped before the ball leaves the player's hand, so that the ball trajectory cannot be seen and used to make predictions. In these videos, further body rotation towards the camera is shown, the ball-throwing hand can be fully seen, and the position of the shooter's right leg and his head direction can be used to make predictions. This this group of videos additionally contained information about the ball-carrying hand and the shoulder width during the last stage of the throwing phase deemed as relevant for anticipation (Hatzl, 2000). Total duration of the videos in this group was around 970ms. The start time of (all of) the videos relative to the ball release point was around 1100ms.

[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.

Procedure

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

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

The participants were shown all 180 videos in randomized order. They were asked to make a decision as quickly as possible regarding the final placement of the ball in the goal. Upon finishing, they were thanked and debriefed. If they requested it, detailed feedback regarding their performance was sent to them via email. The whole procedure lasted about 45 minutes.

Results

Reaction Time

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

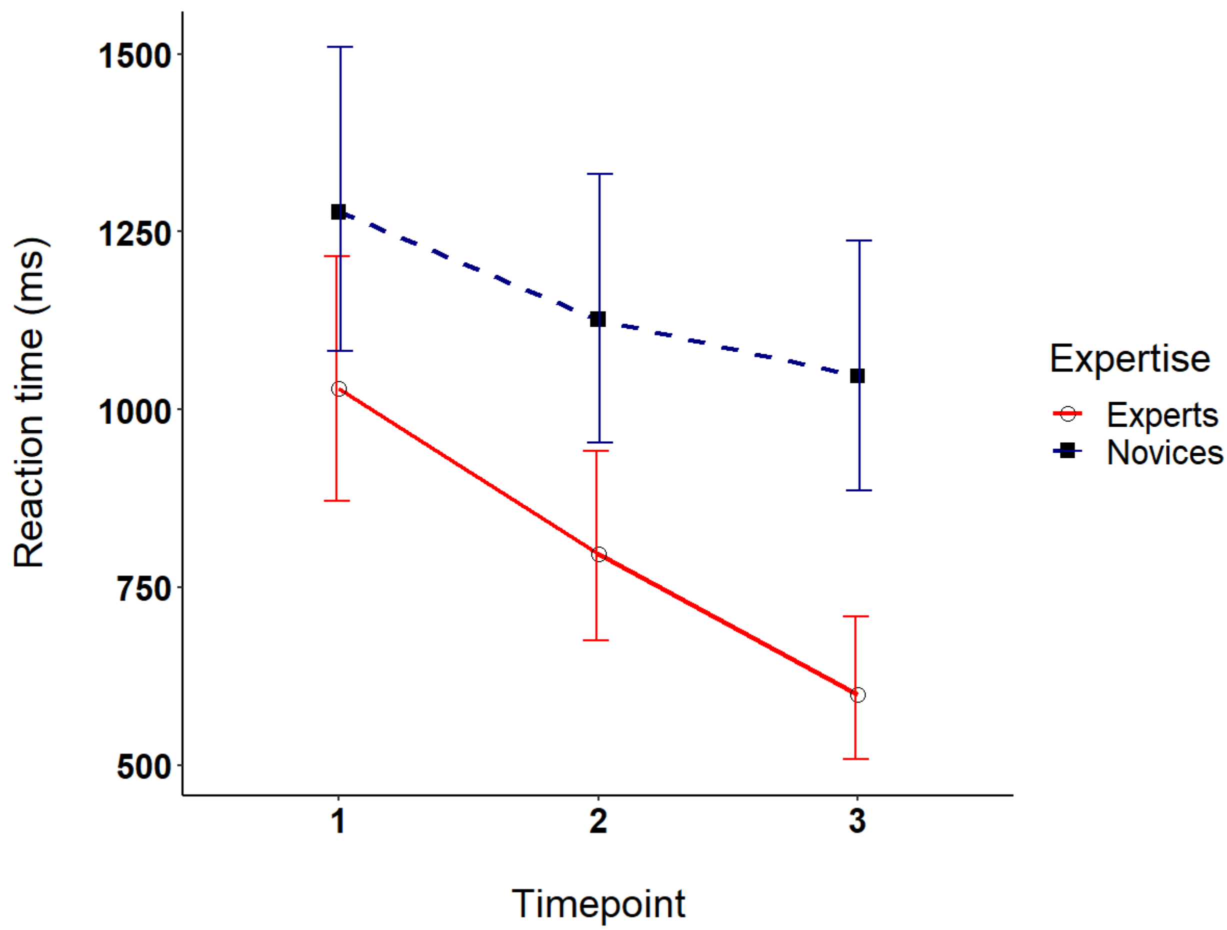

Figure 2. Reaction time of experts and novices at three occlusion points. Error bars represent one standard error (SE).

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

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

Table 1 summarizes the results of the analysis. The linear mixed-effect analysis utilizes standard dummy coding of categorical predictors to estimate the regression coefficients. In particular, one level is dropped from each factor and serves as a referential level with which all other levels and their combinations are compared. The intercept in this type of analysis represents the predicted value of dependent variable (reaction time) for a combination of baseline categories, that is, excluded levels (Expertise: experts, Occlusion point: 1^{st} time point). All other factor levels and their combinations (shown in the Table 1) are consequently compared with the baseline combination of levels. Therefore, the results show that there were no overall significant differences between experts and novices at the first occlusion point (*b* = 0.21, *t* = 0.91, *p* = .35). Experts reacted more quickly at the 2^{nd} (*b* = -0.25, *t* = -8.79, *p* < .001) and 3^{rd} occlusion point (*b* = -0.53, *t* = -18.63, *p* < 0.001) than on the 1^{st} time point. Finally, this difference between 1^{st} and 2^{nd} time point was smaller for novices than for experts (*b* = 0.12, *t* = 3.14, p < .01), as well as, the difference between 1^{st} and 3^{rd} time point (*b* = .34, *t* = 8.30, *p* < .001). To be able to estimate changes from 2^{nd} to 3^{rd} occlusion point, we set the 2^{nd} occlusion point as reference level and re-run the model. As expected, the difference between 2^{nd} and 3^{rd} was significant for experts (*b* = -0.12, *t* = -3.14, *p* < 0.01), while still weaker for novices than for experts (*b* = 0.21, *t* = 5.17, *p* < 0.001). The model with these two factors and by-participant and by-item random structure explained 57% of the variance in reaction time. The variance for intercept adjustment was estimated stronger between participants (variance = 0.27 log RT) in comparison to the variance between items/videos (variance = 0.01 log RT). In other words, different participants respond consistently slower or faster, while different stimuli elicit equally fast responses. The Appendix C illustrates random adjustments for each participant and each item in the reaction time (see Figure C1) and accuracy analysis (see Figure C2).

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

Accuracy

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

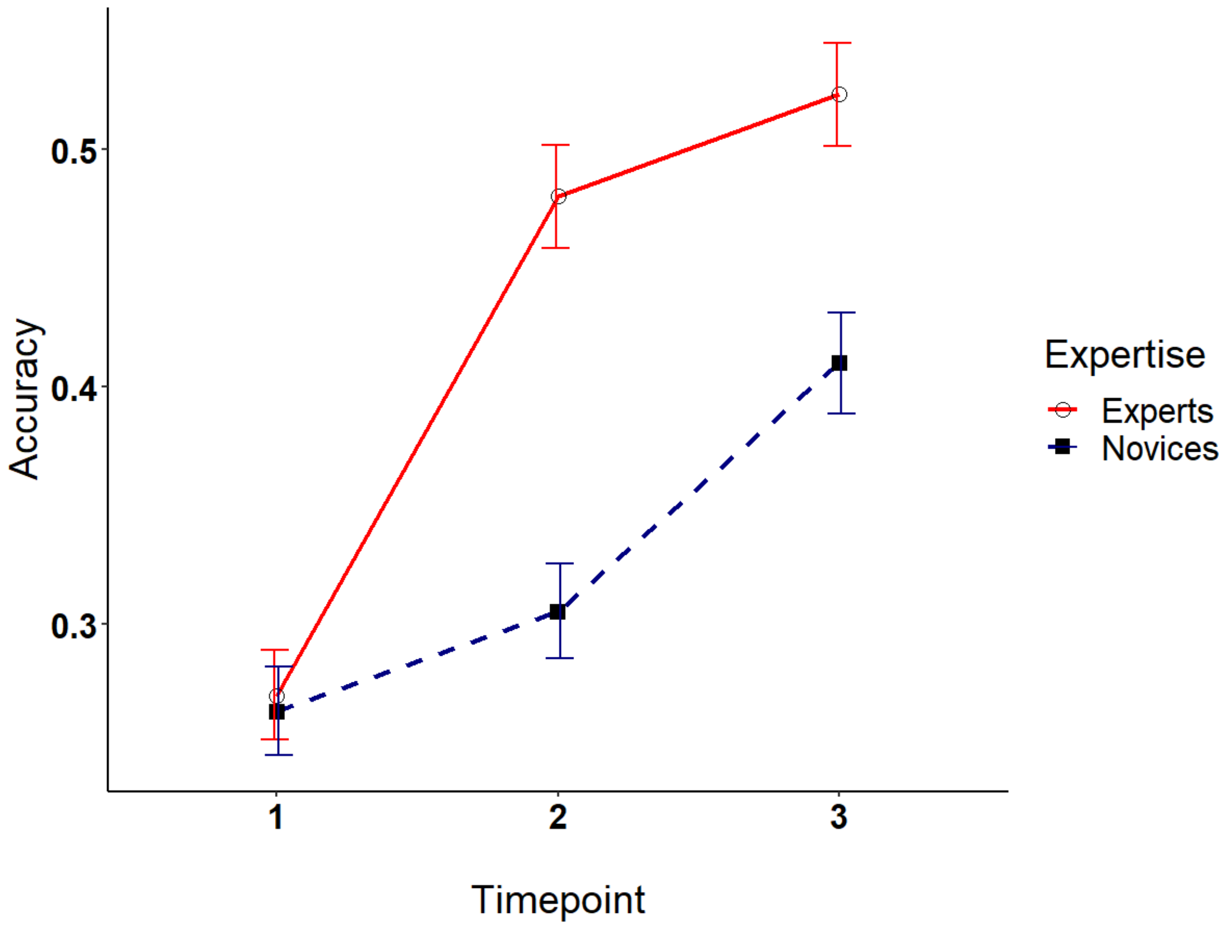

Figure 3. *Accuracy (proportion) of experts and novices at the three occlusion points.*

In the case of the accuracy, we used logistic mixed-effect analysis with the same fixed and random-effect structure as in the analysis of reaction time. Table 2 presents overall significance of factors and their interactions. Similar to the mixed-effect model on reaction time, the model built on accuracy also uses individual data (non-averaged measures), while random effect structure adjusts the estimates from the model by specifying the repeated (clustered) measurements. We specified that dependent variable is following binomial distribution forcing model to calculate regression coefficients in the log-odds space. In other words, we did not separately transform the input to the model, e.g. calculate probability or frequencies per condition, but used the outcomes in their natural format.

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

We also investigated changes of accuracy in anticipation from 2nd to the 3rd occlusion point between experts and novices by changing the referential level of time occlusion factor. In contrast to the results on the reaction time, results show that experts do not benefit from more information between 2nd to 3rd time point (b = 0.16, z = 1.45, p = .14), while novices tend to improve more but the differences did not quite reach the significance level (b = 0.28, z = 1.67, p = .09). The model with these two factors and by-participant and by-item random structure explained 5% of the variance in accuracy. Unlike the reaction time analysis, the estimated variance of random intercepts was higher for items/videos (variance = 0.14) than for subjects (variance = 0.004). The weak contributions of the random structures indicate that all participants respond on task with similar baseline accuracy, while all stimuli elicit similarly accurate responses (see Figure C2 in Appendix). Contrary to this, most of the differences in the accuracy are observed due to the manipulated factors.

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

Discussion

In order to successfully parry a penalty shot in handball, goalkeepers need to anticipate the final destination of the ball even before the ball leaves the thrower's hand. Our results demonstrate well-developed anticipatory skills in handball goalkeepers. Even 400ms before they saw the ball trajectory (occlusion point 2), experts could judge where the ball is going to go considerably above the chance. This ability is acquired, as novices, with far less experience, were consistently worse in anticipation. Both experts and novices could extract more useful kinetic information as the amount of information increased in the subsequent occlusion points (see also, Farrow et al., 2005; Maxeiner et. al., 1996). However, experts were able to identify and utilize the relevant information better and more rapidly than novices (see also, Gredin, Bishop, Tucker & Williams, 2018; Maxeiner, 1988).

Importance of meaningful occlusion points in anticipation research

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

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

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

Similarly, Alsharji (2014) also defined five time windows in his analysis of the ability to anticipate seven-meter shots in handball. However, those time windows included two from when the ball was already released and three which included movement before the release. As mentioned before, reacting only after the ball has been released will not result in a successful save (Schorer, 2006) as it does not leave enough time for goalkeepers to make an informed decision, choose and execute an adequate motor response program. Therefore, information from the last two occlusion points in Alsharji's study (2014) is not informative. Even though the first three occlusion points contained pre-throw movements, the starting point of the sequence was chosen to be in the middle of the movement execution (when the body was already rotated and one could see the thrower's hand clearly). This ignores the analysis of relevant movements for anticipation (e.g Hatzl, 2000) and has consequently resulted in no significant difference between consecutive time windows.

Reaction time in anticipation research

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

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

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

The combination of accuracy and reaction time can also be used to determine the ecological validity of the study. For example, in the German handball Bundesliga, arguably the strongest handball league in the world, goalkeepers save on average about 20% of seven-meter penalties[3]. 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/

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

Future directions and conclusion

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

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

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

Our study demonstrates that kinetic knowledge is the essence of expertise in sport. It also underlines the importance of the definition of meaningful occlusion points in the research on anticipation. Only carefully chosen occlusion points allow insights into how different patterns of movement impact expert ability to anticipate. The importance of this finding extends beyond the laboratory, as only the findings based on meaningful occlusion points can serve as the basis for the training of future experts. Our study identified the crucial occlusion points based on the typical movement analysis (Hatzl, 2000) as well as the time reactions of experts (Schorer, 2006).

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Appendix A

Stimuli creation procedure

Videos used as stimuli in this study were recorded at the University Sport Institute (USI) in Alpen-Adria University of Klagenfurt (Austria). The process of making stimuli took two days. During the first day, we chose adequate camera settings for recording, as well as optimal lighting conditions. The ideal ball colour (blue) was chosen from a few different ones so that it was as distinguishable from the floor colour as possible. We examined the condition of the parquet so as to stay clear from possibly damaged parts, which could impact the way the ball bounces. Finally, the ideal hall temperature was chosen.

Each of the four corners of the goal were taped (see Figure A1) to make it clearer to the handball player being filmed which parts of the goal he was supposed to target while shooting penalty shots (hence making the precision of shots as high as possible). All specificities in these setting were chosen in accordance with a professional handball goalkeeper's counsel. Once all preparations had been made, test filming was conducted with a professional handball goalkeeper.

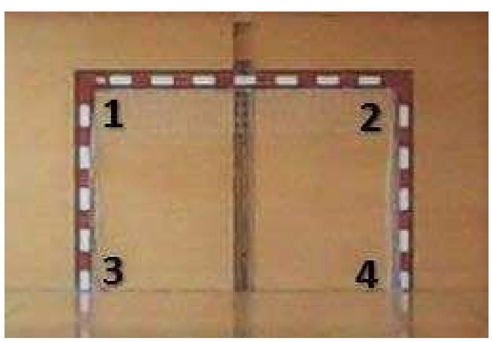

Figure A1. *Goal marks used in the study.*

Based on the insights from trial filming on the first day, the optimal time window was chosen (4 hours) with the best possible conditions for filming. Also, upon viewing the test material, we designed a detailed flow chart of how the process of filming was to be conducted. It was decided that the order of where the seven-meter (penalty) shots were to be aimed was to be randomized.

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

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

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

Appendix B

Classical ANOVA analyses on reaction and accuracy

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

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			

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

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			

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			

Appendix C

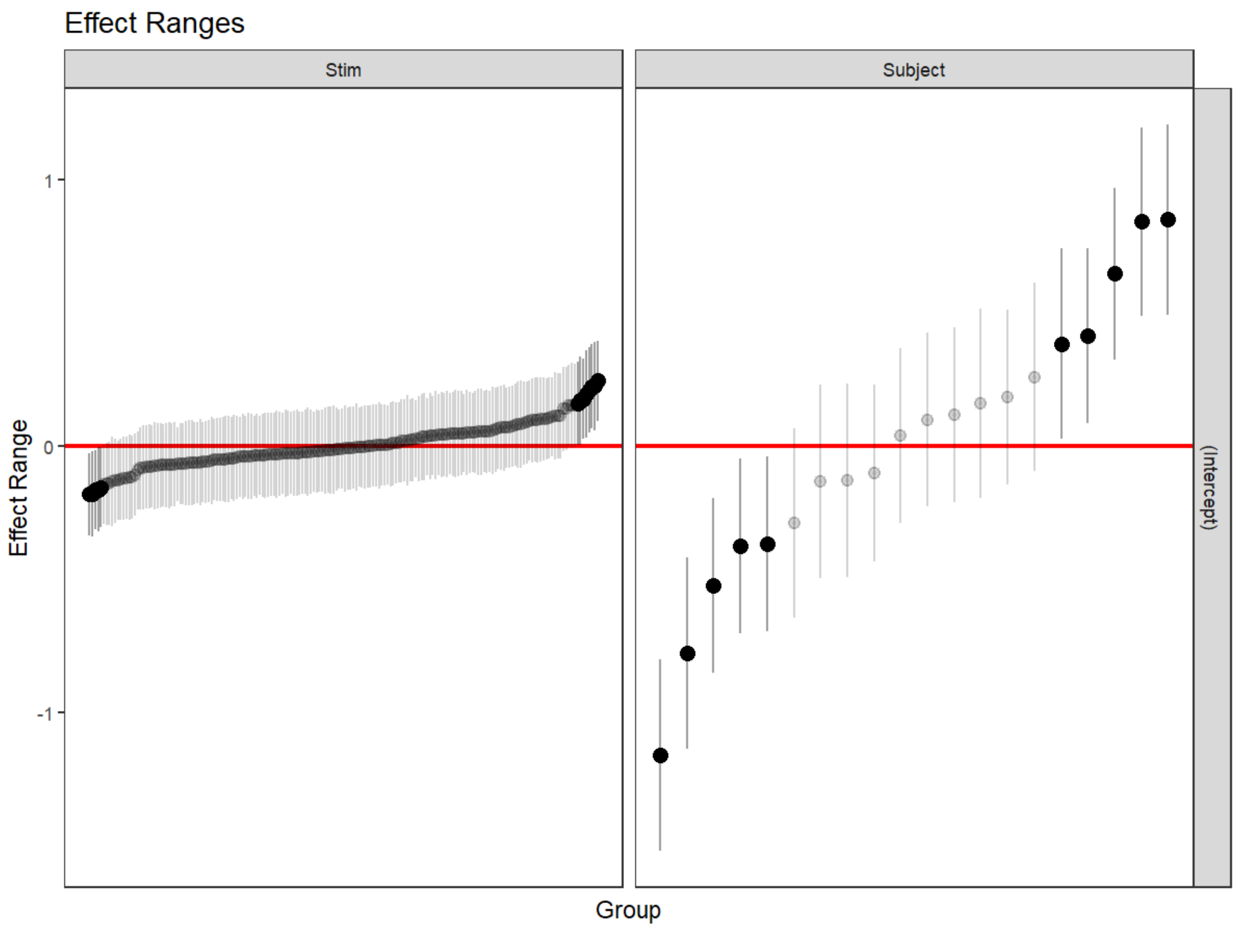

Figure C1. Random adjustments of the intercept in the case of reaction time analysis. Left: random adjustments of the intercept for stimuli (videos); Right: random adjustments of the intercept for participants in the experiment. Red line indicates global estimate of the intercept, while individual estimate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

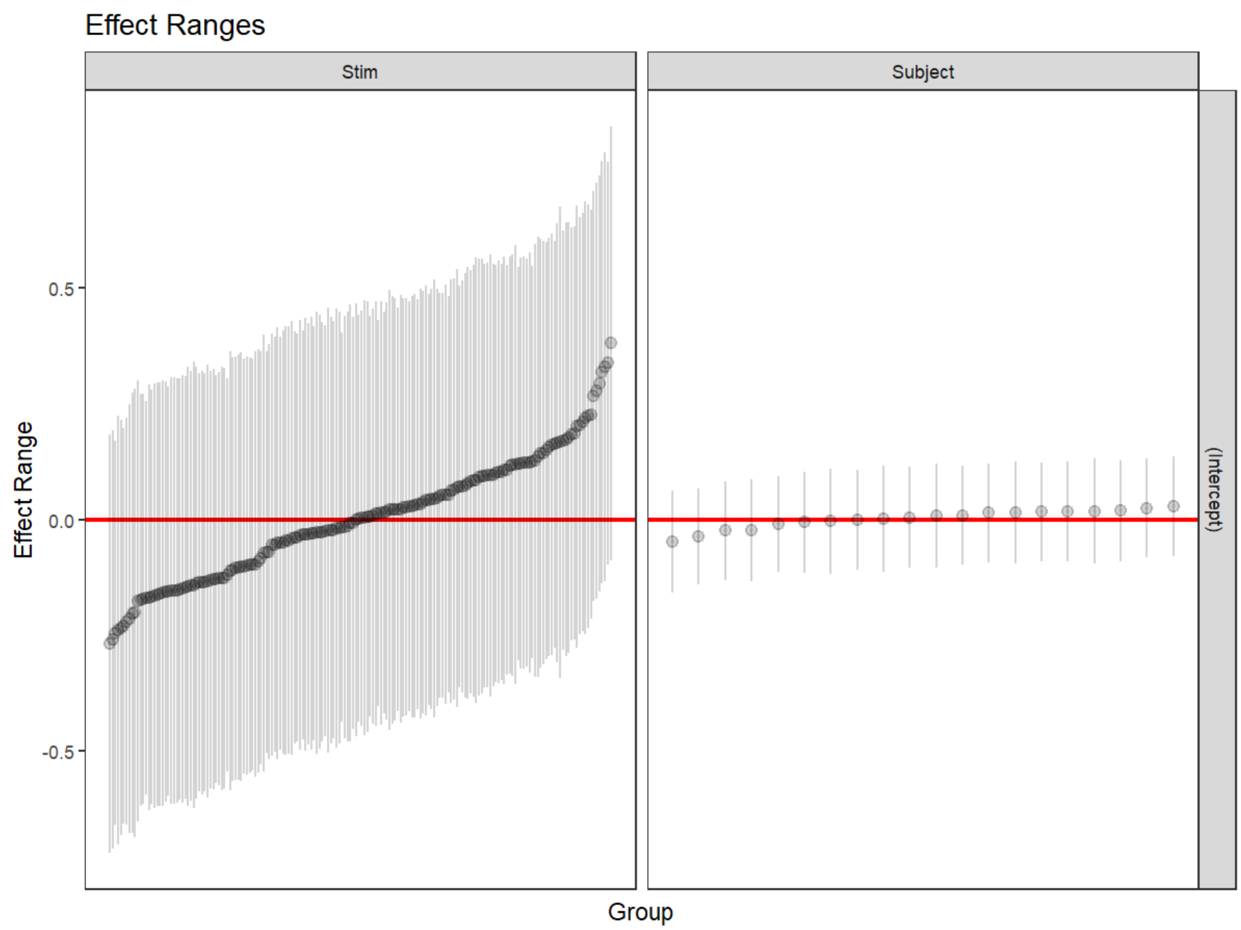

Figure C2. Random adjustments of the intercept in the case of accuracy analysis. Left: random adjustments of the intercept for stimuli (videos); Right: random adjustments of the intercept for participants in the experiment. Red line indicates global estimate of the intercept, while individual estimate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