VU Research Portal

Integrating situational probability and kinematic information when anticipating disguised movements

Helm, Fabian; Cañal-Bruland, Rouwen; Mann, David L.; Troje, Nikolaus F.; Munzert, Jörn

published in

Psychology of Sport and Exercise
2020

DOI (link to publisher)

[10.1016/j.psychsport.2019.101607](https://doi.org/10.1016/j.psychsport.2019.101607)

document version

Publisher's PDF, also known as Version of record

document license

Article 25fa Dutch Copyright Act

[Link to publication in VU Research Portal](#)

citation for published version (APA)

Helm, F., Cañal-Bruland, R., Mann, D. L., Troje, N. F., & Munzert, J. (2020). Integrating situational probability and kinematic information when anticipating disguised movements. *Psychology of Sport and Exercise*, 46, 1-8. [101607]. <https://doi.org/10.1016/j.psychsport.2019.101607>

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal ?

Take down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

E-mail address:

vuresearchportal.ub@vu.nl

Full Length Article

Integrating situational probability and kinematic information when anticipating disguised movements

Fabian Helm^{a,*}, Rouwen Cañal-Bruland^b, David L. Mann^c, Nikolaus F. Troje^d, Jörn Munzert^e^a Department of Psychology and Sports Sciences, Goethe-University Frankfurt, Germany^b Department for the Psychology of Human Movement and Sport, Institute of Sport Science, Friedrich-Schiller-University Jena, Germany^c Department of Human Movement Sciences, Amsterdam Movement Sciences and Institute of Brain and Behavior Amsterdam, Vrije Universiteit Amsterdam, Amsterdam, the Netherlands^d Biomotionlab, Centre for Vision Research and Department of Biology, York University, Ontario, Canada^e Department of Psychology and Sports Science, Justus-Liebig-University Giessen, Germany

ARTICLE INFO

Keywords:

Disguise

Penalty

Bayes

Informational weighting

Non-kinematic information

Situational probability

ABSTRACT

Objectives: The current study sought to examine the relative contributions of kinematic and situational probability information to anticipation using different levels of disguised kinematics. More specifically, it was tested whether the weighting of the informational sources (kinematic vs. probabilistic) shifts relative to the certainty of the available kinematic information.

Design and Method: Human-like avatars were generated performing penalty throws and displayed in a virtual reality environment. The ambiguity of the kinematic information available from the avatars was systematically manipulated using linear morphing between genuine and disguised throws. In a perceptual classification task, trained novice observers ($N = 23$) were asked to classify as quickly and accurately as possible whether observed throws were either genuine or disguised. In addition, information about the performer's action preferences was also systematically manipulated by explicitly informing participants about the performer's AP to disguise their throw (25%, 50%, and 75%).

Results: Participants' response behavior showed that observers relied more heavily on the probabilistic information when the kinematics were ambiguous. For the AP 25% condition, observers were more likely to report that ambiguous throws were genuine ($p < 0.001$), whereas they classified the ambiguous throws as being disguised in the AP 75% condition ($p < 0.001$).

Conclusion: Findings suggest that observers rely more strongly on non-kinematic (situational probability) information when the reliability of the observable movement kinematics becomes less certain.

Anticipating the outcome of an opponent's action is an important skill for coping with temporal demands in competitive interactive sports. Previous research has focused largely on the role of the *kinematic* information for action anticipation, consistently demonstrating that skilled athletes are able to anticipate an opponent's action intentions based on differences in the opponent's observable movement kinematics (see Mann, Williams, Ward, & Janelle, 2007, for a meta-analysis). It is well known that skilled athletes can exploit this anticipatory advantage during competition to respond earlier and more accurately when reacting to the actions of their opponent (Dicks, Davids, & Button, 2010; Farrow, Chivers, Hardingham, & Sachse, 1998). This advantage has been demonstrated in situ and in different lab settings using 2D screens (see Mann et al., 2007 and Travassos et al., 2013, for meta-

analyses) as well as when using virtual reality (VR) (Brault, Bideau, Craig, & Kulpa, 2010; Brault, Bideau, Kulpa, & Craig, 2012; Vignais, Kulpa, Brault, Presse, & Bideau, 2015). However, research that compares VR use with 2D screen lab settings indicates that the use of VR would benefit anticipatory performance. This increase in performance is suggested to be a result of superior ecological validity when using VR (Vignais et al., 2015).

Because athletes rely on kinematic information to aid their performance in competitive scenarios, opponents often perform *disguised* actions in order to keep their opponent in suspense about the impending action intentions, often leading the observer to respond incorrectly (Jackson, Warren, & Abernethy, 2006; Rowe, Horswill, Kronvall-Parkinson, Poulter, & McKenna, 2009). When disguising their action

* Corresponding author. Department of Psychology and Sports Sciences, Johann Wolfgang Goethe-University Frankfurt, Ginnheimer Landstr. 39, 60487, Frankfurt, Germany.

E-mail address: fabian.helm@sport.uni-frankfurt.de (F. Helm).

<https://doi.org/10.1016/j.psychsport.2019.101607>

Received 25 March 2019; Received in revised form 11 October 2019; Accepted 14 October 2019

Available online 19 October 2019

1469-0292/ © 2019 Published by Elsevier Ltd.

Abbreviations in Text

3D	Three-dimensional
ANOVA	Analysis of variance
AP	Action preference
HSD	Honestly significant differences
PCDT	Proportion of classified disguised throws
VR	Virtual reality

intentions, performers attempt to provide their opponent with ambiguous kinematic information to increase the opponent's uncertainty with which they can anticipate the veridical action outcome (cf. Helm, Munzert, & Troje, 2017; Jackson & Cañal-Bruland, 2019). For example,

Rowe et al. (2009) investigated the overall perceptual sensitivity to movement outcomes in the presence of disguise. Their findings showed that observers are significantly less sensitive to action outcomes in situations in which athletes perform disguised (ambiguous) actions. Conversely, sensitivity to action intentions increases when the ambiguity of the kinematic information becomes weaker, for instance, when kinematics are exaggerated spatially (Pollick, Fidopiastis, & Braden, 2001) or temporally (Hill & Pollick, 2000).

To counteract any decrease in sensitivity when anticipating the outcome of disguised movements, athletes might rely on other *non-kinematic contextual* sources of information. Recent research has begun to highlight the importance of contextual information for action anticipation (see Cañal-Bruland & Mann, 2015). Non-kinematic, contextual sources of information include, for instance, (situational) probability

A No Integration Model

B Equal Weighting Model

C Bayesian Integration Model

Fig. 1. Outcome predictions. Subfigures in A show the possible outcome predictions when participants *do not combine/integrate* the kinematic and the AP information for their anticipatory judgment that reflects the use of simple heuristic strategies by ignoring one of the available sources of information. Subfigures B and C show the possible outcome predictions when participants *do combine/integrate* the kinematic and AP information by either giving *equal weight* to both sources of information (subfigure B) or in a way consistent with Bayesian theory by giving *more weight to the more certain* informational source (subfigure C). All outcome predictions are related to the proportion of throws being classified as disguised as a function of the level of disguised kinematics in throws.

Assuming that participants *do not combine/integrate* the informational sources (subfigure A: *No Integration Model*) two outcomes are possible: (A1) Participants rely on the kinematic information only resulting in the psychometric function shown in subfigure A1. When only using kinematics, the psychometric functions would not differ between AP conditions. (A2) Participants rely on the AP information only resulting in constant lines located at the proportional level of the instructed AP values.

Assuming that participants *do combine/integrate* the informational sources two model predictions are made: (B) According to an *Equal Weighting Model* it is assumed that participants would average the contextual and kinematic sources of information without any consideration of the certainty of that information resulting in a linearly increasing proportion of throws classified as disguised as a function of the level of disguised kinematics in throws. These proportions are constantly shifted towards a higher (lower) proportion in the AP 75% (AP 25%) disguised condition with respect to the baseline AP 50% condition. (C) According to a *Bayesian Integration Model* it is assumed that participants would consider the certainty of the two sources of information in order to weight the final perceptual judgment towards the more certain source of information. This weighting of the informational sources would result in a typical sigmoidal behavior of the psychometric functions being shifted towards a higher (lower) proportion of throws classified as disguised in the AP 75% (AP 25%) condition only in the throwing categories where the kinematic information becomes ambiguous (k values 0.25, 0.50, 0.75).

information relating to the likelihood of shot outcomes on the basis of (a) the opponent's position on the court (Abernethy, Gill, Parks, & Packer, 2001; Loffing & Hagemann, 2014; Loffing, Sölter, Hagemann, & Strauss, 2016), playing patterns or preferences related to game scores (Farrow & Reid, 2012; Gray, 2002), or (b) through pattern-induced expectation biases resulting either from experiences of immediate previous sequences of action outcomes (Gray, 2002; Loffing, Stern, & Hagemann, 2015), or based on the knowledge about the general action preference (AP) of an opponent (Mann, Schaefer, & Cañal-Bruland, 2014; Navia, van der Kamp, & Ruiz, 2013). Information about APs are particularly prevalent in elite interactive sports: quite commonly, athletes (e.g. goalkeepers, fullbacks, batters, etc.) study the APs of their opponents in order to enhance their likelihood of success, particularly in situations in which (a) visual motion information (i.e. kinematics or ball flight) is uncertain and/or (b) the time available to initiate a response is particularly low. In some scenarios, relying on implicitly generated (Mann et al., 2014) or explicitly instructed AP information (Navia, van der Kamp, & Ruiz, 2013) may facilitate anticipatory performance.

Contextual and kinematic information are two distinct sources of information that do not only differ substantially in content, but also in their temporal availability. While contextual information (e.g. information about an opponent's AP) is available prior to action execution, kinematic information becomes only available when an opponent's action starts to unfold. Moreover, there are potential differences in the certainty of the informational sources, with the information provided by the movement kinematics more likely to be related to the actual outcome than any preceding contextual information. However, because of the high time constraints in many sports, as well as the possibility that athletes try to disguise their action intentions, kinematics alone may not be sufficient to anticipate action outcomes. Therefore, it seems necessary to combine kinematic and contextual sources of information to generate an integrated judgment that is characterized by the smallest possible response uncertainty.

To date, relatively little is known about if, and if so how, athletes would integrate kinematic and contextual sources of information, or indeed how they would account for situations where the kinematic and non-kinematic information are in conflict (cf. Loffing & Cañal-Bruland, 2017, for a short overview). Scrutinizing how this integration process operates is of utmost importance to improve our theoretical and applied understanding of anticipation and decision-making in sports. It is likely that each of the different informational sources can facilitate or harm the anticipatory processes depending on whether they provide complementary or conflicting sensory input. Moreover, appropriate integration of information sources should consider the amount of (un)certainty from those sources, and their reliability, given a specific action context and/or game situation (cf. Cañal-Bruland, Filius, & Oudejans, 2015; Gray, 2002; Mann et al., 2014).

One possible solution when seeking to solve the integration problem is that the two sources of information could be integrated in a manner consistent with Bayesian decision theory. Bayesian decision theory posits that, when integrating multiple information sources, an ideal decision will be generated by weighting the influence of the informational sources by the certainty of that information. Previous work on perception and sensorimotor learning has demonstrated that in many circumstances humans act in a manner consistent with an ideal Bayesian decision maker (Ernst & Banks, 2002; Körding & Wolpert, 2004; Tassinari, Hudson, & Landy, 2006; see Körding, 2007, and Vilares & Körding, 2011, for reviews). Another possible solution when seeking to solve the integration problem would be to use simple heuristics, a decision strategy that ignores parts of the available information in order to make decisions more quickly and/or accurately (Gardner, 2019; Giegener & Gaissmaier, 2011; Raab, 2012). Research on heuristics in the sports science domain has shown that in some scenarios athletes tend to use simple heuristics, such as to 'take the first', in order to respond as fast and accurate as possible (Raab, 2012).

In the context of interactive situations in sports, a recent study by Gray and Cañal-Bruland (2018) demonstrated in a simulated baseball batting task how probabilistic information about the likelihood of a pitch outcome is integrated with the amount of the informational content about ball trajectory. In their experiments, baseball batters were instructed to hit balls thrown by a simulated pitcher using information about pitch probability and ball flight. To test whether the amount of the informational content of ball flight would influence the integration of the two sources of information, the authors used a temporal occlusion paradigm. With this paradigm the amount of information available from ball flight was manipulated systematically. Results showed that the influence of contextual information about pitch probabilities was larger when occlusion occurred earlier in ball flight as compared to when it was late. These findings suggest that athletes (batters) more heavily rely on situational probability information when they are less certain of the trajectory. However, an important question that was not been addressed in that study is to what degree different levels of ambiguity influence the integration of the kinematic and the probabilistic information. In other words, the batters in the study by Gray and Cañal-Bruland (2018) relied more on contextual information when ball-flight information was removed, but this could have been because of a reduction in the amount of information available, rather than in an increase in the ambiguity of that information. Moreover, it remains unclear how the integrative processes would apply to kinematic information of the type conveyed in an action sequence, rather than that conveyed by ball flight. One way to increase the ambiguity of kinematic information is to disguise movements.

The aim of the present study was to investigate how kinematic and non-kinematic information are integrated when anticipating the action outcomes of others. Specifically, we asked—when kinematic and non-kinematic information would be integrated—whether the informational sources are equally weighted independent of the certainty of the information, or whether the weighting of the informational sources shifts relative to the certainty (unambiguity) of that information (cf. Figure 1).

Human-like avatars of handball throwers were generated and displayed in a stereoscopic VR environment. The ambiguity of the kinematic information available from the avatars was systematically manipulated using linear morphing between a set of disguised and non-disguised (genuine) penalty throws. The linear morphing resulted in a set of seven different stimulus categories that differed in the degree to which the throw was disguised or not. In a perceptual classification task, trained novice observers were then asked to decide as quickly and accurately as possible whether observed throws were either disguised or non-disguised (genuine). Furthermore, we also systematically manipulated information about APs by explicitly informing participants about the performer's AP to disguise their throw (25%, 50%, and 75%). We hypothesized that participants would integrate both the kinematic and non-kinematic (probabilistic) sources of information when making perceptual judgments for their anticipation in a way consistent with a Bayesian Integration Model. We predicted that participants would give greater weight to the AP information when movement kinematics become more ambiguous, and vice versa, that they would give greater weight to the kinematic information when the kinematics become more distinguishable (cf. Figure 1C).

1. Method

1.1. Participants

Twenty-seven participants (seven male) with normal or corrected-to-normal vision took part in this study ($M_{age} = 21.5$ years, $SD = 2.8$). The number of participants was determined by an *a priori* statistical power analysis (given $\alpha = 0.05$, power $[1 - \beta] = 0.95$, and effect size $[f] = 0.25$) assuming a 2×7 repeated measures ANOVA design by means of G*power 3 (Faul, Erfelder, Lang, & Buchner, 2007). Results

suggested a minimum number of twenty-six participants. All participants were handball novices and reported being active in recreational sports but having no other experience in team handball or goal keeping, and reported exercising an average of twice a week in different sports such as association football, basketball, volleyball, or fitness training. Participants gave written informed consent in accordance with the Declaration of Helsinki. Approval for the study was granted by the local ethics committee of the Department of Psychology and Sports Science at Justus-Liebig-University Giessen.

1.2. Stimuli

The experimental stimuli comprised a total of 49 different 7-m handball penalty throws that differed according to the ambiguity in (a) the degree to which the throw was disguised or not, and (b) the direction of the throw. Stimuli were produced using a motion database of in total 394 disguised and 396 non-disguised (genuine) expert penalty throws towards different target locations (see Helm, Troje et al., 2017 for details). To manipulate ambiguity about whether the throw was disguised or not, the kinematic data of the disguised and genuine throws were first averaged separately. The ambiguity of the kinematic information was then manipulated using linear morphing between the averaged disguised and genuine throws using the equation shown in Figure 2A (cf. Helm, Munzert et al., 2017; Pollick et al., 2001). The morphing technique allowed the degree of kinematic ambiguity to be systematically manipulated, with the morphs with 50% disguised (and 50% genuine) kinematics providing the highest levels of kinematic ambiguity. Seven different throwing (stimulus) categories were chosen (cf. Figure 2B): (1) exaggerated genuine throws; (2) genuine throws; (3) morphs with 25% disguised kinematics; (4) morphs with 50% disguised kinematics; (5) morphs with 75% disguised kinematics; (6) disguised throws; and (7) exaggerated disguised throws. To provide variation in outcome for each category, we created seven direction categories (from left to right-targeted throws), resulting in a total of 49 penalty throws.

In order to create the stimuli, in a first step, the kinematic data from the linear morphing were used to construct three-dimensional (3D) body animations using the MoSh algorithm (see Loper, Mahmood, & Black, 2014, for further details on the reconstruction approach). The reconstruction resulted in correlated estimates for the performer's body shape and body motion for each individual penalty throw. These body animations were then animated as human-like avatars in a 3D stereoscopic virtual reality (VR) handball arena using Unity 3D, version 5.5.0 (Unity Technologies, San Francisco, CA, USA). All trials started with a blank arena scene that was displayed for 2s, which was followed by displaying the first pose of the human-like avatar that was frozen for a duration of 1.0–2.0s, ensuring that participants were not able to anticipate the onset of stimulus presentation. Subsequently, the avatar started to move and performed the respective penalty throw until the event of ball release or potential ball release in the disguised trials. After this event, the avatar disappeared. Consistent with the aim to examine the influence of kinematic and contextual information on anticipation, no ball-flight information was visible to the observer.

Fig. 3. Trial structure. Temporal characteristics and graphical details of each individual stimulus of the stimulus set are plotted on the time scale of stimulus presentation. Each stimulus started with a blank scene (2 s) that was followed by a static picture (1–2s) of the first frame of the throwing sequence (0.456–0.656 s) performed by the avatar that disappeared at the moment of (potential) ball release. The display of the next stimulus started after participants pressed one of the two response buttons.

Stimulus duration ranged between 456 and 656 ms. An illustration of the overall trial structure is given in Figure 3, and Video S1 shows a representative throwing stimulus in 2D.

Supplementary video related to this article can be found at <https://doi.org/10.1016/j.psychsport.2019.101607>

Fig. 2. Mathematical description of the linear morphing. Based on the linear equation in Fig. 1A, we used the seven k values shown in Fig. 1B to produce a set of different stimuli that differ in the amount of kinematic ambiguity regarding the performer's action intentions. Morphs with k values lower than 0 or higher than 1 are kinematically exaggerated genuine ($k = -0.25$) and disguised ($k = 1.25$) throws. Morphs in between k values of 0 and 1 contain different levels of kinematic ambiguity whether the throw is disguised or genuine. The morph with the k value equaling 0.5 is the most ambiguous morph containing 50% genuine and 50% disguised kinematic cues in the throw.

1.3. Procedure

In order to familiarize participants with the scenario used during the experiment, participants first completed a practice session which demonstrated the perceptual classification task to be used during the experiment proper. During practice participants viewed four genuine and four disguised penalty throws while simultaneously being informed about the type of throw observed and the characteristics that might help to recognize that type of throw. Participants were seated and fitted with the head-mounted VR display. Real-time head tracking was used to update rendering such that it realistically reflected observer movements and allowed the participants to actively explore the scene by moving and turning their head. Viewing perspective in the VR scene was adjusted to the participants' eye level relative to the ground while standing. For the head-mounted display we used an HTC Vive (HTC Corp., Taoyuan, Taiwan), runtime version 1.01.108. The experimental program was written using Unity 3D, version 5.6.3 (Unity Technologies, San Francisco, CA, USA), and the Unity Steam VR Plugin (Valve Corp., Bellevue, WA, USA).

In the experimental session, in each AP condition participants viewed the 49 throws presented in four runs resulting in the presentation of 196 penalty throws. Short breaks of 90s were provided after each run of the whole stimulus set of 49 throws. Stimuli were presented in a randomized order within each set. In three different randomized AP conditions, we presented the 196 penalty throws and explicitly informed participants about the performer's AP to disguise their throw (AP 25%, AP 50%, and AP 75%), however, the probability of a disguised throw was actually equal in each condition. The AP 50% condition was used as the baseline condition against which the effects of AP information in the AP 75% and AP 25% conditions were tested. After the presentation of each stimulus, participants were prompted to classify whether the observed throw was either disguised or genuine by means of pressing one of two buttons on a game controller. Participants were instructed to do so as accurately and quickly as possible, and it was possible to answer during stimulus presentation. No performance feedback was provided.

In the AP 25% and AP75% conditions, we explicitly told participants that the penalty taker would have an AP although they didn't. In order to control that participants did not figure out – even though we didn't provide feedback about the outcome of throws – that there was no AP in these conditions, and did ignore the AP when making their anticipatory judgments, we analyzed the PCDT values from run 1 to run 4. Single factor repeated measures ANOVAs showed no significant changes in the PCDT values from run 1 to run 4 in either the AP 25% ($F(3,69) = 2.63, p = 0.06, \eta_p^2 = 0.10$) nor the AP 75% ($F(3,69) = 1.11, p = 0.35, \eta_p^2 = 0.05$) condition (cf. Table 1). This implies that participants' likelihood to respond in accordance with the AP information in ambiguous throws did not change from the beginning to the end of each condition.

1.4. Data analysis

Due to technical issues with the game controller for three participants, the data collection for these three participants could not be completed, and hence their data were removed from the analyses. A further participant had to be excluded from the data analysis because the results indicated that the short training session prior to the experimental session had no effect at all (PCDT values remained at chance levels across all stimulus categories), leaving a total of 23 participants whose data were processed for data analyses. In order to verify statistical power after sample size reduction, we conducted a *post-hoc* power analysis (given effect size $f = 0.25, \alpha = 0.05$, sample size $[N] = 23$) with a 2×7 repeated measures ANOVA design by means of G*power 3 (Faul, Erdfelder, Lang, & Buchner, 2007) that resulted in an achieved power $[1 - \beta]$ of 0.93.

On the basis of each participant's responses, the *proportion of*

classified disguised throws (PCDT) was calculated relative to the total number of throws shown in each of the seven different stimulus categories that varied in their level of disguised kinematics (cf. Figure 2) for each of the three different AP conditions. To identify the relative weighting of the informational sources (AP vs. kinematics), we calculated the proportional change in PCDT values for the AP 75% and the AP 25% conditions against the (baseline) AP 50% condition for each individual stimulus category. A 2 (AP Contrast: 25% vs. 50%, 75% vs. 50%) $\times$ 7 (Throwing Category: $-0.25, 0, 0.25, 0.5, 0.75, 1, 1.25$) ANOVA with repeated measures for the factors AP Contrast and Throwing Category was used to determine the effect of informational weighting (AP vs. kinematics) in the seven different stimulus categories. *Post-hoc* Tukey's honestly significant difference (HSD) tests were conducted to determine the cause of significant differences involving more than two means.

2. Results

The results of the classification task for each of the AP conditions are presented in Figure 4. The PCDT values of the baseline AP 50% condition demonstrate a sigmoidal increase as a function of the level of disguise. This result confirms that the linear morphing technique produced stimuli that conveyed different levels of ambiguity and thereby differences in the proportion of throws that were classified as disguised. Similar response patterns were also found for the AP 75% and the AP 25% conditions, indicating that observers were similarly sensitive to changes in kinematics in each of the three AP conditions. However, when comparing the AP 75% and the AP 25% conditions against the baseline AP 50% condition, the PCDT values significantly increased (AP 75%) or decreased (AP 25%) when the movement kinematics became ambiguous (i.e. for the morphs with k values equaling 0.25, 0.5, and 0.75), but not when they were unambiguous ($k = -0.25, 0, 1, 1.25$).

The repeated measures ANOVA for proportional PCDT changes showed a significant main effect for AP Contrast, $F(1, 22) = 49.77, p < 0.001, \eta_p^2 = 0.693$, showing an overall increase (decrease) of PCDT values for the AP 75% (AP 25%) condition, and a significant main effect for Throwing Category, $F(3.12, 68.61) = 3.96, p < 0.01, \eta_p^2 = 0.153$, with overall increased (or decreased) PCDT values in the throwing categories (morphs) with k values equaling 0.25 (or 0.75). The pattern of results concerning the main effects indicates (a) an overall change in response behavior towards the likelihood of the explicitly instructed AP, and (b) an asymmetric amount of PCDT shift when comparing the morphs with k values equaling 0.25 and 0.75 between AP contrasts. In absolute terms, *post-hoc* Tukey HSD tests ($p < 0.05$) for the modulus of the proportional PCDT changes confirmed this asymmetric shift in response behavior by showing a significant effect between the AP contrasts (AP 25% vs. AP 50% vs. AP 75% vs. AP 50%) for the throws with k values equaling 0.25 ($p < 0.01$) but not for throws with k values equaling 0.75 (*ns*) nor 0.5 (*ns*). All other comparisons did not attain significance either. Note that the shift in response behavior between the AP contrasts was also more pronounced when the AP information did not match the level of disguised kinematics in the ambiguous throws (cf. Figure 5).

The most important effect for proportional PCDT changes is shown

Table 1

PCDT values for ambiguous throws per run. Averaged proportions of classified disguised throws are shown for the ambiguous throwing categories (morphed throws with k values 0.25, 0.5, and 0.75) separated for run 1 to run 4 for all AP conditions.

Condition	Run 1	Run 2	Run 3	Run 4
AP 25%	0.415 (0.12)	0.460 (0.13)	0.433 (0.12)	0.402 (0.14)
AP 50%	0.484 (0.09)	0.490 (0.10)	0.491 (0.08)	0.493 (0.11)
AP 75%	0.558 (0.10)	0.573 (0.12)	0.571 (0.12)	0.598 (0.12)

Note. Values in parentheses indicate SD of the group mean.

Fig. 4. PCDT values. Participants' mean proportion of classified disguised throws for all action preference conditions and stimulus categories (level of disguised kinematics in throw). Dashed lines indicate graphs of fitting sigmodal functions to the PCDT values. Error bars report ± 1 SE of the group mean.

by the significant AP Contrast $\times$ Throwing Category interaction, $F(2.43, 53.37) = 24.12$, $p < 0.001$, $\eta_p^2 = 0.523$. *Post-hoc* Tukey HSD tests ($p < 0.05$) showed that the proportional PCDT changes in the most ambiguous stimulus category (i.e. the morph with the k value equaling 0.5) were significantly higher (lower) than in the genuine and exaggerated genuine (disguised and exaggerated disguise) stimulus categories (i.e. morphs with k values equaling -0.25 , 0 , and 1 , 1.25), $ps < 0.01$. In addition, when comparing the proportional change of the PCDT values between the AP 75% vs. the AP 50% and the AP 25% vs. the AP 50% contrast, the *post-hoc* tests indicate significant differences ($p < 0.001$) in the more or less ambiguous stimulus categories (i.e. morphs with k values equaling 0.25 , 0.5 , 0.75), but not for the pure genuine or disguised and exaggerated conditions (cf. Figure 5). The positive vs. negative direction of change confirms the overall shift in response behavior towards the direction of the opponent's AP only

when the movement kinematics became ambiguous (i.e. morphs with k values equaling 0.25 , 0.5 , 0.75). Figure 5 illustrates the changes of result patterns by plotting the change in the likelihood of responding that a throw was disguised as a result of the AP information by subtracting the AP 75% and AP 25% conditions from the AP 50% condition.

3. Discussion

Previous research has shown that athletes can make use of both kinematic and non-kinematic (contextual) sources of information when anticipating the action outcomes of an opponent (see Cañal-Bruland & Mann, 2015). Reliance on non-kinematic information becomes particularly important when opponents attempt to convey ambiguous kinematic information by means of disguised movements in order to hide

Fig. 5. Proportional PCDT change. Mean differences in participants' proportion of classified disguised throws for conditions with AP 75% and AP 25% disguised throws against the baseline AP 50% condition. Error bars report ± 1 SE of the group mean.

their true action intentions. Until now, only a few findings exist that have sought to identify the relative contribution of kinematic and contextual information in sports-related anticipation.

The present findings confirmed that observers integrate both kinematic information and prior knowledge about a performer's APs when anticipating an opponent's actions (cf. Mann et al., 2014; Navia et al., 2013). Our results show that observers were more likely to classify ambiguous movements as genuine when they expected the penalty taker was less likely to produce disguised throws (AP 25% vs AP 50% comparison). Similarly, participants were more likely to classify ambiguous throws as being disguised when they expected the penalty taker to produce disguised throws (AP 75% vs AP 50% comparison). Further, the influence of APs increased commensurate with the degree of ambiguity in the kinematic information. In contrast, AP information did not alter the predictions made when observing genuine or disguised throws, presumably because the kinematic information could be judged with a high degree of certainty. Thus, the behavior of our participants is consistent with the principles of Bayesian integration (cf. Vilares & Kording, 2011), with clear evidence and support for our main hypothesis that participants do *not* use simple heuristic strategies (cf. the *No Integration Model* in Figure 1A), but instead *integrate* kinematic and contextual information by giving more weight to informational sources that have greater certainty (cf. the *Bayesian Integration Model* in Figure 1C) and *not* by simply giving equal weight to both of the available sources of information (cf. the *Equal Weighting Model* in Figure 1B). Converging evidence in perceptual and sensorimotor tasks supports the idea that observers act in a statistically optimal manner when integrating multiple sources of information (Ernst & Banks, 2002; Kording & Wolpert, 2004; Tassinari et al., 2006). These findings have recently been extended to sport-related anticipation tasks, showing that athletes rely more heavily on earlier contextual information when the informative content of ball flight is reduced (Gray & Cañal-Bruland, 2018). However, this behavior might have been a result of the fact that athletes in the Gray and Cañal-Bruland (2018) study had to rely on contextual information due to a reduction in the amount of ball-flight information available, rather than an increase in the ambiguity of that information.

Accordingly, the present findings extend previous research by showing that not only the amount of information, but also the degree of ambiguity of the information alters behavior in sports-related anticipation. The more the movement kinematics become ambiguous, the greater the weight placed on contextual information when forming an integrated perceptual judgment. This outcome is of particular interest, especially when athletes try to manipulate the responses of their opponent by providing ambiguous kinematic information by means of disguise (cf. Helm, Munzert et al., 2017). In those situations, the judgment accuracy of observers is significantly reduced when only kinematic sources of information are available (Rowe et al., 2009), illustrating the importance of integrating non-kinematic information in uncertain cases that would increase likelihood of success.

Contrary to our predictions, the present results do show a strong asymmetric shift of classification performance between the AP 25% vs. AP 50% and the AP 75% vs. AP 50% conditions for the moderately ambiguous stimulus categories (morphs with k values equaling 0.25 and 0.75). On closer inspection, results demonstrate that in situations in which the AP information did not match the level of disguised kinematics in throws, the change in AP information had a significantly stronger effect on classification performance than in situations in which the AP information did match the level of disguised kinematics in throws (cf. Figure 5). One possible explanation for this effect may be that non-matching AP information reduces confidence in both sources of information, with participants more likely to simply guess the outcome rather than rely on either source of information (indeed there is a regression towards the 50% chance guessing level in these situations, see Figure 4). Conversely, it could be that there is a ceiling effect when the prediction from the two sources of information do match,

decreasing the degree to which the contextual information can supplement the somewhat ambiguous kinematic information.

Navia et al. (2013) have shown that anticipatory performance is enhanced when soccer goalkeepers are *explicitly* told that an opponent will direct a higher proportion of kicks in one direction. In that case the explicit instructions were congruent with the actual probability of kicks in the particular direction. In our study, the explicit knowledge of APs was incongruent with the actual action outcomes in the AP 75% and AP 25% conditions. The proportional PCDT values for these conditions, as well as the fact that participants' likelihood to respond in accordance with the AP information in ambiguous throws, did not change from the beginning to the end of each condition (cf. Table 1). This behavior demonstrates that observers still rely on the ultimately incorrect AP information when the movement kinematics of the stimulus material were ambiguous (uncertain), resulting in less correct judgements. It is argued that observers give more weight to the supposedly certain AP information, irrespective of whether that information is potentially misleading, in order to anticipate the outcome of the observed actions when the movement kinematics seem to be ambiguous. Mann et al. (2014) assumed that exposure to a particular pattern of preferred action outcomes is detrimental to anticipatory performance when opponents act inconsistently with the implicitly generated expectations of the observer. The current findings extend those findings to the context of explicitly generated expectations by showing that an observer's reliance on explicitly instructed AP information can also be disadvantageous to performance when this information is in conflict with the actual probability of possible action outcomes (i.e. types of penalty throws).

4. Conclusion

Taken together, our findings lead to three main conclusions. First, athletes seek to optimize anticipatory judgements by integrating kinematic and non-kinematic contextual information in a manner consistent with Bayesian integration whereby the contribution of the sources of information is weighted by its certainty. Second, contextual information may be more influential in altering anticipatory behavior when the predicted outcome from contextual information conflicts with that conveyed by kinematic information. And third, the reliance on explicitly generated expectations about an opponent's AP can be detrimental to performance when those expectations do not match the actual probability of the possible action outcomes.

Funding

This research was partly supported by DFG IRTG 1901 "The Brain in Action".

Author contributions

FH: Designed and programmed the experiment, designed and performed the analysis, contributed to the data acquisition, and wrote the manuscript. RCB: Contributed to the development of the experimental design, the design of the analysis, and the writing of the manuscript. DLM: Contributed to the design of the analysis, and the writing of the manuscript. NFT: Contributed to the technical development of the experiment and the production of the stimuli. JM: Contributed to the development of the experimental design and the writing of the manuscript.

Declaration of competing interest

None.

Acknowledgments

The authors thank Britta Hinneberg and Lars Grosse for their

support in data acquisition. We also thank Raphael Schween for his helpful comments on the data analysis.

References

- Abernethy, B., Gill, D. P., Parks, S. L., & Packer, S. T. (2001). Expertise and the perception of kinematic and situational probability information. *Perception*, 30, 233–252. <https://doi.org/10.1068/p2872>.
- Brault, S., Bideau, B., Craig, C., & Kulpa, R. (June 2010). Balancing deceit and disguise: How to successfully fool the defender in a 1 vs. 1 situation in rugby. *Human Movement Science*, 29(3), 412–425. <https://doi.org/10.1016/j.humov.2009.12.004>.
- Brault, S., Bideau, B., Kulpa, R., & Craig, C. M. (2012). Detecting deception in movement: The case of the side-step in rugby. *PLoS One*, 7, e37494. <https://doi.org/10.1371/journal.pone.0037494>.
- Cañal-Bruland, R., Filius, M. A., & Oudejans, R. R. (2015). Sitting on a fastball. *Journal of Motor Behavior*, 47, 267–270. <https://doi.org/10.1080/00222895.2014.976167>.
- Cañal-Bruland, R., & Mann, D. L. (2015). Time to broaden the scope of research on anticipatory behavior: A case for the role of probabilistic information. *Frontiers in Psychology*, 6, 1518. <https://doi.org/10.3389/fpsyg.2015.01518>.
- Dicks, M., Davids, K., & Button, C. (2010). Individual differences in the visual control of intercepting a penalty kick in association football. *Human Movement Science*, 29, 401–411. <https://doi.org/10.1016/j.humov.2010.02.008>.
- Ernst, M. O., & Banks, M. S. (2002). Humans integrate visual and haptic information in a statistically optimal fashion. *Nature*, 415, 429–433. <https://doi.org/10.1038/415429a>.
- Farrow, D., Chivers, P., Hardingham, C., & Sachse, S. (1998). The effect of video-based perceptual training on the tennis return of serve. *International Journal of Sport Psychology*, 29, 231–242. <https://doi.org/10.1080/02640410252925143>.
- Farrow, D., & Reid, M. (2012). The contribution of situational probability information to anticipatory skill. *Journal of Science and Medicine in Sport*, 15, 368–373. <https://doi.org/10.1016/j.jsams.2011.12.007>.
- Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavioral Research Methods*, 39, 175–191. <https://doi.org/10.3758/bf03193146>.
- Gardner, J. L. (2019). Optimality and heuristics in perceptual neuroscience. *Nature Neuroscience*, 22, 514–523. <https://doi.org/10.1038/s41593-019-0340-4>.
- Giegerenzer, G., & Gaissmaier, W. (2011). Heuristic decision making. *Annual Review of Psychology*, 62, 451–482. <https://doi.org/10.1146/annurev-psych-120709-145346>.
- Gray, R. (2002). Behavior of college baseball players in a virtual batting task. *Journal of Experimental Psychology: Human Perception and Performance*, 28, 1131–1148. <https://doi.org/10.1037/0096-1523.28.5.1131>.
- Gray, R., & Cañal-Bruland, R. (2018). Integrating visual trajectory and probabilistic information in baseball batting. *Psychology of Sport and Exercise*, 36, 123–131. <https://doi.org/10.1016/j.psychsport.2018.02.009>.
- Helm, F., Munzert, J., & Troje, N. F. (2017). Kinematic patterns underlying disguised movements: Spatial and temporal dissimilarity compared to genuine movement patterns. *Human Movement Science*, 54, 308–319. <https://doi.org/10.1016/j.humov.2017.05.010>.
- Helm, F., Troje, N. F., & Munzert, J. (2017). Motion database of disguised and non-disguised team handball penalty throws by novice and expert performers. *Data in Brief*, 15, 981–986. <https://doi.org/10.1016/j.dib.2017.10.042>.
- Hill, H., & Pollick, F. E. (2000). Exaggerating temporal differences enhances recognition of individuals from point light displays. *Psychological Science*, 11, 223–228. <https://doi.org/10.1111/1467-9280.00245>.
- Jackson, R. C., & Cañal-Bruland, R. (2019). Deception in sport. In A. M. Williams, & R. C. Jackson (Eds.), *Anticipation and decision making in sport* (pp. 99–116). Abingdon, Oxon: Routledge.
- Jackson, R. C., Warren, S., & Abernethy, B. (2006). Anticipation skill and susceptibility to deceptive movement. *Acta Psychologica*, 123, 355–371. <https://doi.org/10.1016/j.actpsy.2006.02.002>.
- Körding, K. (2007). Decision theory: What “should” the nervous system do? *Science*, 318, 606–610. <https://doi.org/10.1126/science.1142998>.
- Körding, K. P., & Wolpert, D. M. (2004). Bayesian integration in sensorimotor learning. *Nature*, 427, 244–247. <https://doi.org/10.1038/nature02169>.
- Loffing, F., & Cañal-Bruland, R. (2017). Anticipation in sport. *Current Opinion in Psychology*, 16, 6–11. <https://doi.org/10.1016/j.copsyc.2017.03.008>.
- Loffing, F., & Hagemann, N. (2014). On-court position influences skilled tennis players' anticipation of shot outcome. *Journal of Sport & Exercise Psychology*, 36, 14–26. <https://doi.org/10.1123/jsep.2013-0082>.
- Loffing, F., Sölter, F., Hagemann, N., & Strauss, B. (2016). On-court position and handedness in visual anticipation of stroke direction in tennis. *Psychology of Sport and Exercise*, 27, 195–204. <https://doi.org/10.1016/j.psychsport.2016.08.014>.
- Loffing, F., Stern, R., & Hagemann, N. (2015). Pattern-induced expectation bias in visual anticipation of action outcomes. *Acta Psychologica*, 161, 45–53. <https://doi.org/10.1016/j.actpsy.2015.08.007>.
- Loper, M., Mahmood, N., & Black, M. J. (2014). MoSh: Motion and shape capture from sparse markers. *Proceedings SIGGRAPH Asia*, 6, (pp. 1–13). <https://doi.org/10.1145/2661229.2661273>.
- Mann, D. L., Schaeffers, T., & Cañal-Bruland, R. (2014). Action preferences and the anticipation of action outcomes in penalty situations. *Acta Psychologica*, 152, 1–9. <https://doi.org/10.1016/j.actpsy.2014.07.004>.
- Mann, D. T. Y., Williams, A. M., Ward, P., & Janelle, C. M. (2007). Perceptual-cognitive expertise in sport: A meta-analysis. *Journal of Sport & Exercise Psychology*, 29, 457–478. <https://doi.org/10.1123/jsep.29.4.457>.
- Navia, J. A., van der Kamp, J., & Ruiz, L. M. (2013). On the use of situation and body information in goalkeeper actions during a soccer penalty kick. *International Journal of Sport Psychology*, 44, 234–251. <https://doi.org/10.7352/IJSP2013.44.234>.
- Pollick, F. E., Fidopiastis, C., & Braden, V. (2001). Recognising the style of spatially exaggerated tennis serves. *Perception*, 30, 323–338. <https://doi.org/10.1068/p3064>.
- Raab, M. (2012). Simple heuristics in sports. *International Review of Sport and Exercise Psychology*, 5, 104–120. <https://doi.org/10.1080/1750984X.2012.654810>.
- Rowe, R., Horswill, M. S., Kronvall-Parkinson, M., Poulter, D. R., & McKenna, F. P. (2009). The effect of disguise on novice and expert tennis players' anticipation ability. *Journal of Applied Sport Psychology*, 21, 178–185. <https://doi.org/10.1080/10413200902785811>.
- Tassinari, H., Hudson, T. E., & Landy, M. S. (2006). Combining priors and noisy visual cues in a rapid pointing task. *Journal of Neuroscience*, 26, 10154–10163. <https://doi.org/10.1523/jneurosci.2779-06.2006>.
- Travassos, B., Araújo, D., Davids, K., O'Hara, K., Leitao, J., & Cortinhas, A. (2013). Expertise effects on decision-making in sport are constrained by requisite response behaviours: A meta-analysis. *Psychology of Sport and Exercise*, 14, 211–219. <https://doi.org/10.1016/j.psychsport.2012.11.002>.
- Vignais, N., Kulpa, R., Brault, S., Presse, D., & Bideau, B. (2015). Which technology to investigate visual perception in sport: Video vs. virtual reality. *Human Movement Science*, 39, 12–26. <https://doi.org/10.1016/j.humov.2014.10.006>.
- Vilares, L., & Körding, K. P. (2011). Bayesian models: The structure of the world, uncertainty, behavior, and the brain. *Annals of the New York Academy of Sciences*, 1224, 22–39. <https://doi.org/10.1111/j.1749-6632.2011.05965.x>.