Anticipation in sport
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Anticipation has become an increasingly important research area within sport psychology since its infancy in the late 1970s. Early work has increased our fundamental understanding of skilled anticipation in sports and how this skill is developed. With increasing theoretical and practical insights and concurrent technological advancements, researchers are now able to tackle more detailed questions with sophisticated methods. Despite this welcomed progress, some fundamental questions and challenges remain to be addressed, including the (relative) contributions of visual and motor experience to anticipation, intraindividual and interindividual variation in gaze behaviour, and the impact of non-kinematic (contextual or situational) information on performance and its interaction with advanced kinematic cues during the planning and execution of (re)actions in sport. The aim of this opinion paper is to shortly sketch the state of the art, and then to discuss recent work that has started to systematically address open challenges thereby inspiring promising future routes for research on anticipation and its application in practice.

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Factors contributing to the prediction of action effects in sports
Two broad categories of information sources can be differentiated that contribute to the prediction of action effects in sports \([5,6]\): kinematics of the opponent and non-kinematic (or contextual) sources of information. The efficient pick-up and use of information emanating from these sources may be governed by different factors related to domain-specific (visual and/or motor) expertise. Key findings from recent research on anticipation alongside the respective methodological approaches taken are illustrated below.

Kinematic information
An experts’ superiority over their less skilled counterparts in predicting opponents’ action intentions based on the opponent’s kinematics has been identified in early work \([7]\) and confirmed repeatedly since \([2,8]\). While the kinematics’ relevance for anticipation is intuitive, answering what kinematic cues are used and how the cues are picked up is certainly not trivial. To address this issue, researchers employ and occasionally combine different experimental paradigms such as the temporal \([9^{**},10]\) or spatial \([11,12]\) manipulation of a video showing an opponent’s action (Figure 1). In addition, an opponent’s movement is visually reduced to its underlying relative motion (point-light displays, Figure 1c, \([13,14,15^{**}]\) or
researchers track participants’ gaze behaviours [16,17] (e.g. for a review, see Ref. [18]).

**Information pick-up strategies**

Abernethy and Russell [19–21] pioneered the work on information pick-up strategies underlying successful anticipation using selectively occluded film fragments to determine the differences in anticipation between expert and novice squash and badminton players. More recently, Williams *et al.* [14] manipulated selected body regions (e.g. shoulders, hips, arm-racket area) of an opponent hitting tennis forehand groundstrokes and presented the actions as point-light animations stopping at the moment of racket-ball-contact. Participants viewed the videos on a screen and were asked to predict whether shots would be directed to their left or right. Results revealed that skilled tennis players relied on different body areas (i.e. shoulders, hips, legs, arm-racket), whereas their less skilled counterparts were merely affected by the manipulation of the arm-racket area. Hence, skilled players were supposed to use a ‘global’ information pick-up strategy as opposed to less skilled players who appear to primarily rely on local end-effector information (see also Ref. [13]). Similar findings have also been reported for handball goalkeeping [11]. Presenting normal videos of penalty-throws where selected body parts were either removed or shown in isolation (cf. Figure 1b), Loffing and Hagemann demonstrated that skilled and novice goalkeepers were capable of predicting the type of throw (hard vs. soft shot) above chance level solely based on ball-hand information, but only the skilled group clearly benefited from the availability, and suffered from the removal, of distal (throwing arm and the ball) and proximal regions (upper body). The kinematic cues...
informing skilled anticipation as well as the predictive power of selected local body areas, however, is likely to vary across sports (e.g. cricket [12], badminton [22]) and even between tasks within the same sport (e.g. tennis [23]).

**Gaze behaviour**
An efficient information pick-up requires that athletes direct their visual attention to (often by means of gazing at) the most relevant body areas when observing an opponent executing an action. A meta-analysis [8] on eye-tracking research suggests that, compared to novice or less skilled athletes, experts employ a more efficient visual search strategy by directing their gaze to information-rich areas – not necessarily specific body parts but also regions that enable the pick-up of information surrounding gaze location (i.e. visual pivot, [24]) – using fewer fixations of longer duration. There is increasing awareness, however, that summary statistics of gaze data may lead to premature conclusions, for example, regarding skill-specificity in gaze behaviour [25]. Likewise, *intraindividual* and *interindividual* variation [26] as well as differences in gaze behaviour as a function of task demands (e.g. in soccer goalkeeping [27]) suggest that more sophisticated analyses and interpretation of gaze data are required in future research.

**Training kinematic cue usage to improve anticipation skill**
Those body areas or segments that have been identified to underpin successful anticipation by means of the above mentioned methods, have been implemented in sport-specific perceptual-cognitive trainings. Such interventions have been proven successful in improving novices’ ability to predict opponents’ action outcomes [28,29]. Consequently, it may provide one additional means to foster talent development in sports [3]. However, several issues such as structure of practice, transfer to the field, sustainability of training effects [4] or optimal instruction and feedback techniques to promote both rate of learning and robustness of skill-recall under stress [30,31] have yet to be examined in more detail.

**Visual and motor experience**
Visual experience has been identified as an important factor driving the prediction of an opponent’s action intention. In support of this and suggesting specificity in skilled anticipation, the outcome of perceptually less familiar left-handed actions seems harder to predict compared to more commonly exposed right-handed actions in tennis [32], volleyball [33,34] or handball goalkeeping [35], irrespective of an observer’s handedness [32].

However, athletes’ anticipation skill may also benefit from their perceptual-motor expertise, although relative contributions of the respective components are still unknown [10,36,37]. Moreover, there is growing evidence of a particular involvement of the motor system in skilled anticipation [38,39]. For example, Aghiots *et al.* [38] showed that elite basketball players (high visuo-motor expertise) made earlier and more accurate predictions about the outcome of basketball free-throws (options: ‘in’, ‘out’, ‘don’t know’) than a group of expert watchers (journalists and coaches; high visual expertise) and novices (no experience in basketball). Moreover, only motor experts (basketball players) were found to specifically display higher corticospinal activation recorded from the hand (abductor digiti minimi) during the observation of ‘out’ as compared to ‘in’ shots occluded shortly after the ball left the hand, suggesting that motor expertise as opposed to visual expertise enables fine-tuned motor resonance that may ultimately facilitate action outcome prediction (see also Refs. [40,41]).

Albeit promising, recent evidence of a motor system involvement in anticipation in sports stems from situations that either do not require anticipation in the real world (e.g. darts, [39]) or where (high) time-pressure is absent (basketball free-throw, [38]). Therefore, whether the motor system substantially contributes to the prediction of action effects in (highly) time-constrained dynamic sport situations (e.g. batting in baseball or cricket) is one important question sport psychologists need continue to work on. Providing a clearer picture on this can help establish a differentiated understanding of the link between perception, cognition and action as well as inform sport practitioners about new potentials in improving anticipatory skill.

**Non-kinematic (contextual or situational) information**
Players’ actions are embedded in sport- and task-specific contexts. They constantly change dependent on, for instance, game score, field position or sequences of consecutive actions in tennis rallies. Also, athletes often know their opponents from previous competitions and/ or performance profiles. Although work published as early as in the late 1970s hinted at the fact that these exemplar non-kinematic sources of information can be used to guide anticipatory behaviour [42,43], systematic research on their contribution to anticipation in sport is limited (for a recent opinion article arguing along the same lines, see Ref. [6]). Knowledge of likelihoods or probabilities about the occurrence of certain events had early been shown to quite strongly influence a player’s anticipatory movements, even before their opponent’s movement information becomes available. These promising research ideas and findings, for unknown reasons, however remained dormant until an influential paper on anticipation in squash appeared in 2001 [9**]. More specifically, in an on-court experiment Abernethy *et al.* found that even before the opponent had initiated their movements, experts performed above chance and better than less-skilled players in anticipating the outcome of the actions

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that were yet to be executed. The authors concluded that experts must have relied on probabilistic information unrelated to kinematics, dubbed *situational probabilities*, and identified the opponents’ court position to be a likely candidate to convey such information.

That paper has inspired a handful of researchers across the globe to broaden their research focus both to develop theory and guide practice on skilled anticipation in sports [6]. The rather isolated work of different research groups led to the identification of several (non-kinematic) sources of information that may affect anticipatory performance in the sport domain [44***]. These sources of probabilistic information include, for instance, an opponent’s court position [9**,15**,45], action patterns associated with certain game scores [46,47], knowledge of action preferences [48*,49] or of general action occurrence [12,50], familiarity with a particular opponent [51] or action [52] or sequences of action outcomes [47,53].

For example, in tennis, Farrow and Reid [46] identified game score as one source that may provide situational probability information and thereby facilitate anticipation. Participants were asked to predict the location of serves presented as video as soon as they felt confident knowing it. Game score was manipulated in a way that it provided advance probability information about shot direction of the first service in a game. Across twelve simulated service games, older but not younger players picked up on and used the information conveyed by game score as indicated by progressively earlier (but constantly correct) predictions.

Relying on situational probability, however, may not be beneficial under all circumstances. Mann et al. [48*] exposed two groups of skilled handball goalkeepers to penalty takers that either had or did not have strong preference to throw towards a particular corner of a goal. Results revealed that if, in the test situation, penalty takers behaved according to the previously shown action preference, anticipatory performance improved. Conversely, if penalty takers did not behave according to their previously shown action preference, goalkeepers’ performance declined (see also Ref. [49]). Although these findings may appear trivial in some respects, they illustrate the need for a differentiated view on the facilitating versus hindering impact of situational variables on anticipation (see also Refs. [47,53]).

As another example, Cañal-Bruland et al. [50] analysed the movement patterns of baseball batters facing fastballs (fast type of pitch) and change-ups (a slower type of pitch) to examine to what degree following the ‘sitting on a fastball’ strategy (*i.e.* to always expect a fastball) impacts on batters’ movement responses. Results showed that in cases where change-ups were not successfully hit, batters had failed to adjust (*i.e.* slow down) their movement initiation patterns, but rather showed movement patterns that were typical for responses to fastballs. Hence, expectations (*e.g.* informed by instructions or action strategies) can influence motor responses in highly time-constrained situations [47]. One important question relates to how situational probabilities can be optimally communicated to athletes [54].

**Conclusions**

As discussed in this paper, players use and rely on both kinematic and non-kinematic sources when planning and executing their (re)actions. A central question for future research pertains to how these sources interact with respect to their respective contribution to the prediction of action effects [6,55]? Models on sensorimotor control may suggest a solution (*e.g.* Bayesian integration, [56]), but evidence originating from more direct testing in a sport-related setting is scarce. Recent work indicates that information related to kinematics and context may be weighted differently during anticipatory processing, resulting in a dynamic updating of expectations in the course of an opponent’s unfolding movement [15**,45]. The relative contribution of kinematic vs. contextual sources to anticipation, however, may further vary as a function of several factors such as task constraints [57], performance pressure [58*] or game situation [55].

In addition, future research needs to address pertinent methodological questions such as whether video-based testing may fall short when trying to capture skilled anticipation, and hence whether it is necessary to consider real-life testing [59] that includes the true actions under scrutiny [60,61]. Further promising routes that may fundamentally improve our understanding include studying skill transfer between domains or tasks [62] and scrutinizing individual differences in more detail [63,64].

**Conflict of interest**

We have no potential conflict of interest to report.

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**References**


Testing experienced and novice dart players’ ability to predict the outcome of dart throws under varying additional task conditions, the authors demonstrate that only experienced players’ accuracy decreased when they had to simultaneously perform an action-incongruent motor task. Findings are interpreted as evidence of a motor system involvement when experienced players predict action effects.
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Using focused interviews with elite beach volleyball players (e.g. Olympic or world champions), the authors reveal that players’ decision-making in defensive situations depends on a number of factors related to their opponents and context. Findings stimulus new approaches for research on the interplay between visual information, gaze behaviour and domain-specific knowledge.


Using a video-based experiment on handball goalkeeping, the authors demonstrate that knowledge of an opponent’s action preference may benefit or harm goalkeepers’ predictions, depending on whether an opponent actually acts according to her preference or not. Findings indicate that contextual information (e.g., action preference) may also turn out detrimental to performance.


Testing skilled and less-skilled tennis players’ ability to anticipate an opponent’s stroke outcome in tennis under high and low anxiety conditions, results tentatively indicate that availability of contextual information may be less helpful to players under high as opposed to low anxiety conditions. The authors speculate that an anxiety-induced shift in players’ attentional control may have contributed to this effect.


