Part I

Characteristics of expert anticipation in sport

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Postural cues, biological motion perception, and anticipation in sport

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Introduction

It is well established that the ability to anticipate what will happen next is an important component of successful performance in many sports, particularly racket sports and team ball games (Williams, Ford, Hodges, & Ward, 2018). The need to anticipate arises due to the significant spatial and temporal constraints that exist in many sports, necessitating that information be processed in relatively short periods of time so as to enable athletes to plan and execute a timely response to their opponents' actions. Some examples of situations where anticipation is important include the penalty kick in soccer, the tennis serve, and batting in baseball or cricket. The initial work on anticipation focussed almost exclusively on the ability of athletes to pick up early or advance, most notably postural, cues from an opponent's movements (i.e. information arising from an opponent's biological motion) ahead of a key event, such as when a player's foot or racket makes contact with the ball (Williams, Fawver, Broadbent, Murphy, & Ward, in press). However, recently researchers have reported that anticipation is dependent on the ability to process a range of different sources of information interactively and dynamically as the action unfolds (e.g. pattern recognition, context, probabilistic information) as opposed to relying exclusive on the pickup of postural cues (Williams, Broadbent, Murphy, & Janelle, in press). Yet it remains apparent that the pickup of postural cues can help guide anticipation either independent of or in conjunction with other perceptual-cognitive skills. At the very least, the pickup of postural cues may confirm or reject the accuracy of any initial judgements made based on other sources of information (Cañal-Bruland & Mann, 2015; Triolet, Benguigui, Le Runigo, & Williams, 2013).

In this chapter, we review more than four decades of research that has focussed on identifying the postural cues that are crucial to anticipation in sport. The main objective is to highlight the various approaches that have been used to examine postural cue usage in sport. Generally, the aim in this body of research has been to identify what cues are picked up, when these sources of information become available, and how such information is processed. In the opening sections, we review research using traditional methods such as film-based temporal and spatial occlusion, point-light displays, and liquid crystal occlusion glasses to identify both when and what information is picked up during anticipation. The conceptual approach in these early studies was heavily grounded in cognitive psychology using terms such as cue usage and information extraction. Next, we review a more recent body of research, grounded more so in ecological psychology and dynamical systems theory, that makes use of sophisticated data analysis and modelling methods, such as principal component analysis (PCA) to better identify how information is perceived as well as when and what information sources are important. In this latter approach, anticipation is not constrained by a single cue, or even a collection of cues, but rather is an emergent process due to athletes becoming attuned to the biological motions emerging from the opponent's actions. Finally, we propose that a more detailed understanding of the biomechanical constraints imposed on the actions to be anticipated will reveal greater insight into what information is perceived and offer suggestions for future research in this area of study. In order to further delimit the scope of the chapter, we do not review studies in which researchers have attempted to identify the information sources underpinning anticipation using eye movement registration systems, nor do we consider the implications of the findings reported for perceptual-cognitive training. Similarly, the influence of attempts by opponents to disguise key cues or deceive the observer is not discussed in this chapter.

Identifying when key cues are picked up: the temporal occlusion paradigm

One of the earliest published reports focussing on the importance of anticipation in sport was carried out in tennis using the film-based temporal occlusion method (Jones & Miles, 1978). The authors presented participants with filmed images of an opponent serving in tennis from a first-person perspective. Participants viewed each serve and were required to anticipate where on the court the opponent was going to play the ball by marking a response on a scaled, schematic representation of the court. At various time points relative to ball-racket contact, the film was occluded in order to prevent access to later arising sources of information. The footage was occluded either 42 ms before, at, or 335 ms after the racket made contact with the ball. Participants were constrained to make a judgement based on information available up to the point of occlusion, which in the earlier occlusion conditions meant that decisions had to be made based on cues emerging from the server in advance of ball flight information. A group of expert tennis players was much more accurate in making anticipation judgements when compared to another group of less expert players, with accuracy scores significantly above chance in the former group, even in the earliest occlusion condition. The expert tennis players were able to pick up postural cues from the opponent ahead of ball contact in order to enable them to successfully anticipate where the ball was likely to land on their side of the court.

This seminal finding led to a plethora of related research using the film-based temporal occlusion paradigm. The generalisability of the findings was explored across a range of different sports, including squash (Abernethy, 1990), badminton (Abernethy & Zawi, 2007), baseball (Moore & Müller, 2014), cricket (Abernethy & Russell, 1984), soccer (Williams & Burwitz, 1993), volleyball (Wright, Pleasants, & Gomez-Meza, 1990), and field hockey (Starkes, 1987), to name only a few sports. The ensuing research largely confirmed the importance of being able to pick up advance postural cues when anticipating an opponent's actions in sport. Although the key time period for information extraction has been shown to be sport- and task-specific, and to interact with the availability of other sources of information (Roca, Ford, McRobert, & Williams, 2013), a consistent observation is that experts are better than non-experts at picking up the key cues underpinning anticipation. Moreover, with increasing levels of expertise, players are able to extract information from progressively earlier stages in the action (Müller, Abernethy, & Farrow, 2006). An illustration of various temporal occlusion points is presented in Figure 1.1.

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Perhaps the most notable progress made in the decades that followed was refinement of the methods used to explore research questions. Advances in technology enabled 16 mm film to be replaced with higher resolution digital video footage, and the advent of digital editing software allowed for easier and more accurate editing (Williams, Davids, & Williams, 1999). A shift occurred away from using pen-and-paper responses and towards more realistic movement-based response modes, often incorporating sophisticated measurement devices, such as infrared beams, pressure-sensitive floor mats, and optoelectronic motion capture systems (Müller & Abernethy, 2006; Oudejans & Coolen, 2003; Starkes, Edwards, Dissanayake, & Dunn, 1995). Similarly, life-size projection screens were more frequently used, as were, more recently, three-dimensional video projectors, igloo-style wrap-around video screens, 360-degree video, and virtual reality (Williams et al., in press). Also, efforts were made to move outside of the laboratory and explore the phenomenon *in situ* using, for example, video-based, time-use analysis methods (Abernethy, Gill, Parks, & Packer, 2001; Triolet et al., 2013) and computer-controlled liquid-crystal occlusion goggles to occlude vision (e.g. Farrow & Abernethy, 2003). While such advances in technology inevitably enhanced measurement sensitivity, the overall conclusions remained largely consistent in highlighting the importance of picking up the key postural cues as early as possible in the action.

Identifying what cues are picked up: the spatial occlusion paradigm

A shortcoming with the temporal occlusion approach is its inability to isolate the specific sources of information used during anticipation. In order to identify what cues are important, the temporal occlusion approach has to be combined with event or spatial occlusion, or alternative methods, such as eye movement recording and think-aloud verbal protocols (see Williams & Ericsson, 2005). When employing the spatial occlusion approach, the information sources deemed to be important are either occluded (i.e. masked) or removed, usually for the entire duration of the clip. However, the approach may be used in conjunction with the temporal occlusion paradigm in order to simultaneously examine the ‘what’ and ‘when’ questions.

Specific cues thought to be informative, such as the hips of the penalty taker in a soccer penalty kick or the server's arm and racket in the tennis serve, are removed from view using a mask (e.g. black box) or by digitally editing the video to replace the source with the background so that the source effectively disappears. Any decrement in performance in the occluded condition relative to a non-occluded control suggests that the source of information must play a role in anticipation either on its own or in conjunction with other cues (e.g. Causer, Smeeton, & Williams, 2017; Jackson & Mogan, 2007; Müller et al., 2006; Williams & Davids, 1998). An alternative approach involves presenting a cue (e.g. the hips) in isolation with no additional information presented. If performance scores are above chance when only this single cue is presented, the implication is that this information is sufficient to guide anticipation (e.g. Causer et al., 2017; Müller et al., 2006). Some typical spatial occlusion conditions are presented in Figure 1.2.

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While film-based approaches have been most widely used in this field of study, researchers have used point-light and stick-figure displays, which are routinely employed in classical literature on biological motion perception (e.g. Abernethy et al., 2001; Abernethy & Zawi, 2007; Cutting, Proffitt, & Kozlowski, 1978; Shim, Carlton, & Kwon, 2006; Ward, Williams, & Bennett, 2002). In this approach, typically optoelectronic motion capture methods are employed to create point-light displays of sports actions, such as a forehand drive in tennis. These images can then be manipulated in much the same way as film-based occlusion methods, with the overall aim being to identify what cues are important and when they are extracted. The approach has the advantage of being able to remove access to background and structural information, ensuring that only the relative motions between limbs remain in an effort to better isolate the minimal information needed to facilitate skilled perception. A typical point-light image of a tennis player performing a forehand drive shot is presented in Figure 1.3, alongside a stick-figure representation.

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Innovative recent methods: principal component analysis

A shortcoming with spatial and temporal occlusion is that they only provide information relating to the key information time windows and body regions underpinning anticipation. Moreover, when researchers use the occlusion approach they have to select *a priori* the time point or body region thought to be informative. As a result, there is potential for subjective bias in the selection of the regions thought to be informative. In an effort to address these limitations, researchers have more recently used PCA to try and isolate essential movement patterns and examine the value or contribution of the information contained in these patterns to successful anticipation (Bourne, Bennett, Hayes, & Williams, 2011; Diaz, Fajen, & Phillips, 2012; Huys, Smeeton, Hodges, Beek, & Williams, 2008).

PCA is used on time-series analyses to isolate structures or components that capture a proportion of the total variance in the data set that is orthogonal to the other components (for a tutorial, see Daffertshofer, Lamoth, Meijer, & Beek, 2004). Such an analysis is used to reduce the dimensions of a data set into fewer components or structures. From this analysis, the results are analysed by focussing on: (i) the amount of variance captured by each of the components, (ii) the projection (time evolution) of the components, and (iii) the eigenvector coefficients that provide weightings to the components. The amount of variance captured by each component is ordered or ranked according to the percentage of variance captured. If PCA is successful in reducing the dimensions of the data set, there is a higher than average percentage of variance captured in the principal components, and consequently, the amount of variance captured in the later components is reduced. The projection associated with the component indicates how the data evolve over time. If the components are independent, they will have unrelated time evolutions. Typically, this issue is examined statistically by calculating the covariance between the projections associated with the components. Finally, the eigenvector coefficients indicate the weighting of each time series analysed with PCA on to the component. If a time series contributes a large amount to the component, a high coefficient is reported, whereas a low weighting onto a component is indicated with a low coefficient. These coefficients can be positive or negative, indicating a positive or negative contribution to the component.

PCA has become popular in the motor control literature over recent decades because of its link to contemporary theories of human movement. In particular, it is been used to provide insights into how movements are coordinated and controlled (e.g. see Kelso, 1997; Scholz & Schoner, 1999). It is possible to examine the motions of many body regions and their biomechanical linkages at the same time, consistent with the view that these linkages do not act in isolation (Bernsteĭn, 1967). The potential for data to be separated into movements that have a large amount of coherence and structure over time, and those that have less so implies that the principal components captured result from a predictable process, and, consequently, they may be perceived to anticipate outcomes. The components that capture less of the variance may be considered as containing a high degree of 'noise' and may not contribute functionally to the movement. Additionally, inter-individual or inter-trial differences that exist appear in the lower components that capture less of the overall variance compared to those movements that are consistent between individuals or trials. This process can be thought of as 'distilling' the repeated attempts of an action to its fundamental movements that are consistently found across individuals.

How PCA may be used to identify dynamic motion structures underlying anticipation

The first published report using PCA in sport attempted to identify the dynamic motion structures underpinning anticipation in tennis (Huys et al., 2008). The rationale was that the visual information underlying anticipation is captured in the motion structures or principal components evident in the kinematic profiles of athletes. Huys and colleagues (2008) collected kinematic data from tennis forehand shots struck to near and far, inside-out, and cross-court target locations, from six nationally ranked, right-handed tennis players. Retroreflective markers were placed on 18 joint locations on the arm and racket of each tennis player. The resulting 5,184 variable data matrix was subjected to PCA to compare tennis shots across participants and locations. PCA was successful in reducing the dimensions of the data set into its key principal components.

The first three principal components captured approximately 90% of the variance across tennis shots, with the first five components contributing over 95% of the variance. Within the first three components, there were substantive contributions from the arm and racquet linkage, which was greatly reduced in the fourth and fifth component, despite the data being rescaled to remove any larger weightings resulting from the arm and racket having the largest amplitude in the tennis shots action. This finding is consistent with the rationale that PCA identifies structured features in the data and therefore offers information to perceive action outcomes. To identify the dynamical differences for different shot outcomes, the eigenvector value weightings corresponding to body locations in the Cartesian coordinate directions were compared for inside-out (i.e. down-the-line) and cross-court shots directed to near and far targets. More substantive differences in eigenvectors value weightings were reported for shots that differed laterally (i.e. cross-court vs. inside-out) across the first five modes. These significant differences were located across nearly all body locations, supporting a view that the information used to anticipate is not contained in a single anatomical area (or cue), or one or even a few body regions, but is distributed globally across the body. The key information was most consistently found in the right side of the body in the x-direction for the right-handed tennis players. Also, the left arm and right leg were shown to make a contribution; these were body regions that had not previously been identified via spatial and temporal occlusion methods. There was not a single component that was uniquely associated with shot direction. It was the differential contribution of body regions to the components that distinguished tennis shot outcomes, and these were located across all body regions to varying degrees (Figure 1.4).

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Subsequently, Bourne et al. (2011) used PCA to examine kinematic differences in handball throws to four different target directions. They reported that components were not qualitatively different between throw directions and that the first three components captured approximately 90% of the variance in the action. While they reported differences in the size of eigenvector coefficients contributing to the components, analysis of the first component revealed no significant differences across the four different target locations. A novel aspect of their design was the use of three equally spaced time windows in order to identify when dynamic structures become more relevant as ball release approached. However, no differences were reported across throw directions in the eigenvector coefficients. It was concluded that subtle movements in the wrist and hand differentiated across the four throw locations in handball, but generally their analysis methods were not sensitive enough to identify these subtle differences.

While whole body PCA is not the best tool for identifying what these subtle movements are, the idea that one can manipulate the trajectory of the wrist to affect throw direction particularly late in the action raises an important question about why these results differ from Huys et al. (2008). Potentially, the higher-skilled athletes used by Bourne et al. (2011) may have had a greater level of coordination and muscular control than the intermediate tennis players. As a result, they would have been able to change the wrist and hand trajectory to alter throw outcomes while keeping the dynamics of the rest of their body the same. The less-skilled tennis players may not have been able to achieve this feat. Additionally, the tennis players' use of a tennis racket, and the much shorter period of time in which the racket is in contact with the ball compared to a handball throw, may constrain them to change the dynamics of their actions when hitting balls to different locations. Consequently, differences in action outcomes were identified using whole body PCA in tennis but not handball.

There is some evidence to support the idea that task-based differences may influence the results of PCA. Higueras-Herbada, Travieso, Ibanez-Gijon, and Jacobs (2017) used PCA to examine kinematic data gathered from players taking penalty kicks in soccer. The greater amount of variance captured in the first mode (approximately 70%) in comparison with variance (circa 50–55%) reported by Huys et al. (2008) and Bourne et al. (2011) may confirm the inclusion of a horizontal approach (i.e. a run-up). However, the total variance captured in the first five components was similar (approximately 95%). No data were presented on the dynamical differences between different kick directions.

Identifying the principal components underpinning anticipation

The use of PCA to identify outcome differences in the kinematics of sports actions does not mean that these same components provide information to the perceiver during anticipation. Huys et al. (2008) were the first to examine this issue. In two experiments, the information contained within principal components was compared using a film-based anticipation test. In the first experiment, stick-figure simulations were created using the results of the PCA. Six conditions were created where components from 1 to 5 were cumulatively summed and compared to the 'original' tennis shot containing the entire variance. Because the PCA used to create the simulations was based on the overall PCA across all participants, the individual differences between participants' dynamics had been removed. The results showed that only Components 1–3, which contained approximately 90% of the variance, were needed to obtain anticipation performance comparable with that reported in the full vision, control condition. It was concluded that Components 1–3 contained sufficient information to be able to successfully anticipate above chance levels. An under-explored finding from this experiment was a tendency for Components 1–5 on their own to be anticipated with greater accuracy than the original shot. A suggestion is that the 'lower' components may contain movement noise, and when these components are added to the higher components the information becomes harder to perceive because the perceptual system has to distinguish between the information and the noise. Potentially, skilled anticipation may result from the ability to *distinguish* between the key information needed for anticipation and noise in the system.

In the final experiment, a further six conditions were created by combining components. Components 1 and 2, 1 and 3, 2 and 3, 6 and 7, and 8–20 were presented alongside the original shot. The main finding was that anticipation was above chance levels in all component combinations, showing that even information from components that capture a very small proportion of the variance can be used to support anticipation. Huys et al. (2008) interpreted these findings from a coordination dynamics perspective. An intriguing idea presented was that the components themselves may be informational. The rationale for this suggestion is that because the components (1) are captured by way of their shared covariance and (2) are orthogonal to the other components, they may, in informational terms, be distinct. This view is consistent with the idea that information for anticipation is globally specified. Additionally, the movements captured have a large amount of coherence and structure over time, and imply that the principal components captured result from a deterministic process, which is by nature coupled with a specific outcome. One challenge for this hypothesis is to provide experimental evidence that the component itself is the information for anticipation rather than containing the information. An alternative proposal is that the principal components provide the information for the action to be recognised as, for example, a tennis forehand. That is, the components are the dynamical information for the class of an action. In this case the information for anticipation would be contained in the components rather than by the components themselves.

Few researchers have examined the informational role of the components for anticipation. In one recent exception, Higueras-Herbada et al. (2017) showed simulations of soccer kicks to left and right directions based on PCA. As per Huys et al. (2008), they cumulatively summed Components 1–6. In the analysis of low and high performers, they showed that the summing components increased the accuracy of judgements when anticipating the direction of soccer kicks. However, more components were required than those in Huys et al. (2008) to attain performance at the level found when viewing the original action. This latter finding may reflect the fact that a soccer penalty kick has more distinct dynamics (e.g. the run-up) that contribute to outcome direction than a tennis forehand groundstroke.

Global and local information for anticipation from PCA

A number of researchers have manipulated the information presented in the simulations based on PCA analysis. Huys et al. (2009) examined the role of locally defined dynamic information when anticipating the direction of tennis forehand shots. In two experiments, the authors either occluded the body locations of stick-figure simulations in a manner comparable with spatial occlusion or used a novel procedure in which the trajectory of a body location identified from PCA was the average of that for left and right shots. The neutralisation methodology was shown to disrupt the dynamics of the action to a lesser extent than the occlusion protocol. The condition where the arm was occluded led to the largest decrement in performance for perceptually skilled individuals, with smaller decrements observed when the shoulders, hips, and legs were occluded. In the second experiment, neutralisation of the dynamical differences in the arm and racket, trunk and legs reduced anticipation performance. Significant correlations were reported between anticipation accuracies in the neutralisation conditions, suggesting that information corresponding to these regions is picked up collectively. This idea is consistent with the view that more reliable information will be extracted if a global search strategy is used. The nature of these correlations indicated that information is extracted in regions proximal and distal to the end effector. Consistent with previous suggestions in the literature, dominant evolution of this information may be in a proximal to distil sequence towards the end effector. Previously, this evolution has been thought to originate in the trunk, but an alternative suggestion is that it may evolve from the contact point with the ground (i.e. the legs). Skilful extract of this information may result from regions more distant from the end effector being used. In a follow-up experiment, Williams, Huys, Cañal-Bruland, and Hagemann (2009) reported that skilled anticipators were affected by the manipulation of information in proximal and distal regions, whereas less-skilled anticipators were only affected by manipulations of the distal regions.

An alternative approach to examining the informational role of the end effector was used by Smeeton, Huys, and Jacobs (2013). It may be the case that information in the end effector prevents novices from employing a more global information extract strategy. Based on the notions of perceptual learning (Jacobs, Runeson, & Michaels, 2001; Jacobs, Silva, & Calvo, 2009), it was hypothesised that novices can get 'stuck' on attending to weaker information residing in a local region (i.e. the end effector compared to global information across more than one region) because performance is perceived by the novice to be 'good enough'. Consequently, they do not explore and discover more reliable information, and skill learning is stunted. To examine this issue, a form of reduced usefulness training was employed that contrasted the traditional approach of augmenting or directing attention to information-rich body regions. Here information in body regions thought to be used by novices was removed. In the second experiment in the paper, shot direction differences in the training stimuli were either present only in the end effector and neutralised in the other body regions (End Effector group) or present only in the other proximal regions (Rest of the Body group). Whilst both groups increased their performance, there were differences in the body regions used to anticipate. In the post-training test, the Rest of the Body group performed significantly better in the condition where information was present in all body regions, suggesting the use of a global search strategy. Presumably this effect occurred because perception was constrained to not 'stuck' on weaker information. However, in the End Effector group performance was only significantly better when information from the shoulder region was present, suggesting a more localised information extraction strategy and the lack of discovery of more reliable information. In the third experiment, the same training stimuli were used as in Experiment 2, but an occlusion approach was used instead of the neutralisation method. In this case, the Rest of the Body group failed to learn, whereas the End Effector group improved their performance. Furthermore, the ability of the latter group to extract information was found in regions other than the end effector. One interpretation of these results is that simply promoting a global search strategy is enough to improve anticipation performance. An intriguing alternative is that the information for anticipation perceived from one body region may be present in other body regions and therefore may facilitate the transfer of anticipation performance to other body regions, perhaps by way of these regions having a shared contribution to the dynamical structures identified through PCA. PCA has provided a useful method for investigating global and local informational contributions to anticipation. However, the methodology of PCA requires that all body regions included in the analysis contribute to a component. Furthermore, it is not possible to separate the time evolution of the components into phases of the action. This limitation makes it difficult to distinguish between a global information extraction strategy whereby information is extracted simultaneously across body regions and one where information is extracted sequentially from local sources as the action unfolds (e.g. from proximal to distal sources).

PCA vs. alternative informational sources for anticipating outcomes

It is possible that other sources of information may provide information to help guide anticipation. In the initial study by Huys et al. (2008), differences between tennis shot directions were reported in analyses other than PCA. Joint location trajectories by way of their amplitude (as measured by the standard deviation of the time series) differed between inside-out and cross-court shot directions. To examine this experimentally, the amplitude differences were compared to the dynamical differences (i.e. the components captured through PCA) by Smeeton and Huys (2011). Skilled and less-skilled tennis players anticipated simulated shots that had the dynamical differences and/or amplitude differences for inside-out and cross-court shot directions either present or absent. Participants performed better in the conditions where the dynamical differences were present, regardless of the presence of the amplitude differences. This result indicates that the dynamical differences rather than the amplitude differences contain information for anticipating directions.

In a study designed to identify the information used to predict penalty kick direction, Diaz et al. (2012) investigated the role of local sources (non-kicking foot yaw, yaw between the midpoint of the ball and point of contact, kicking shank pitch and yaw, kicking foot yaw) and distributed sources (Modes 12, 13, and 15) identified through PCA. Mode 12 was characterised as having a relatively larger contribution to the kicking foot and hands. Mode 13 was characterised as having a relatively larger contribution to the left forearm, left and right feet, and right forearm motions, whereas Mode 15 was more evenly distributed across left and right arms, hands, legs, and feet. All of these sources were identified through an analysis, indicating that they were at least 75% reliable in predicting kick direction. Four sources of information appeared to be used by successful anticipators: yaw angle of the hips, ball-foot contact yaw, Mode 12, and Mode 15.

In a subsequent experiment, the researchers either maintained the information in the hips (making all other information uninformative), made the ball contact point uninformative, or used the normal stimulus. After training, anticipation accuracy was above chance in the normal and ball unreliable conditions. In their analysis of individuals, participants who were able to judge kick direction on the normal trials were also able to judge kick direction on the ball unreliable trials but could not judge kick direction on trials that only retained hip orientation information.

They interpreted this finding as strong evidence against the isolated use of local information sources, even when they arose from reliable local sources, such as the hips and information related to the location of ball-foot contact, but they did not rule out sequential use of local information sources. One might also question the ability to perceive information from Components 12 and 15, given the small amount of variance captured in the lower components. The authors argued that whilst the variance in the dynamic motion may be small, these differences may be perceivable when combined with amplitude, which is typically evened out across time series in the normalising procedure. This suggestion could account for the significant differences reported by Huys et al. (2008, Experiment 3), where information was found in Components 8–20.

Alternative approaches to PCA in identifying information for visual anticipation

PCA has proved useful in capturing the information available for anticipation, but some researchers have argued that it does not specifically identify the nature of the information that is actually used. Higueras-Herbada et al. (2017) have advocated the use of discriminant analysis so that the to-be-perceived properties of the action are related to categorical outcome variables (e.g. left vs. right). Using a binary or other categorical outcome variable may reduce the precision with which use of information can be assessed (Savelsbergh, Williams, Van der Kamp, & Ward, 2002; Stevenson, Smeeton, Filby, & Maxwell, 2015). Lopes, Jacobs, Travieso, and Araujo (2014) used a correlation and regression analysis to identify single and compound kinematic variables that were associated with the lateral deviation of a penalty kick in football at various time points. Weak correlations were found between candidate kinematic variables and lateral deviations prior to 500 ms before ball-foot contact. Non-kicking foot angle, the angle of the kicking leg, and kicking foot speed showed the strongest correlations before ball-foot contact. At contact, kicking foot angle, hip angle, and kicking foot movement direction correlated most strongly with lateral deviation. In the regression analysis, compound variables were found to be better predictors of lateral deviation. Such a finding supports the view that information for anticipation is most reliable when it is derived from multiple regions over time, although it does not allow for a distinction between global extraction of information and sequentially extracted local information.

Perception of inertia as information for anticipation

One under-explored biomechanical principle that constrains action outcomes is the body's resistance to change in motion, that is, the inertial constraints acting on the person being anticipated. Forceful striking of objects and the launching of projectiles towards particular locations require that athletes overcome the inertia of body segments (Hamill & Knutzen, 2009). There is a relatively larger inertial constraint acting on a tennis forehand drive, which involves swinging a tennis racket that extends some length beyond the hand, than that acting on a handball throw where the ball is held in the hand. If the inertial constraints are large enough, then this would result in a high probability that the current movement pattern would be maintained and as a consequence be more predictable. However, if this was not the case, then it is greater potential for that the movement pattern to change. Anticipation occurring under the latter circumstance anticipation is vulnerable to error and, on average, is less likely to be successful. In movements where the end effector is relatively more constrained by inertia, such as tennis forehand drives, modifying the tennis shot direction to the left or right side of the court requires earlier application of force to overcome the inertial constraints of the action compared to those that are less constrained, such as a handball throw. Due to this requirement, the probability of the tennis shot direction changing would decrease earlier in the swing, and as a result the likelihood of successful anticipation ofthe outcome increases. However, in actions such as a handball throw, differences in throw direction can be achieved by small and rapid changes to the wrist and hand trajectories (Bourne et al., 2011). As a result, inertia provides a relatively small constraint on the throw direction early in the action sequence, and anticipation would be more vulnerable to errors because it is harder to successfully anticipate the throw direction until later in the action sequence. Consequently, in addition to perceiving the movement pattern of body segments, it may be the case that skilled anticipators perceive the inertial constraints acting on another person from the movement patterns in the body segments.

The predicted effects of the aforementioned inertial constraints on anticipation are consistent with data from temporal occlusion studies. Temporal occlusion studies show that accuracy typically increases towards the end of the action (e.g. Farrow, Abernethy, & Jackson, 2005). The inertial constraints on actions mean that increasingly greater force would need to be produced to alter the trajectory of the end effector and, consequently, the shot direction outcome as it evolves towards the strike or throw release point. In anticipation terms, this application of force would require a large movement of other body segments. As a result, it would be more easily perceived. It is predicted that early in an action, striking balls less forcefully, such as that seen in a chip penalty kick would be less accurately anticipated than striking the ball forcefully with the instep of the foot. There is greater potential for the chip action to be modified later in the action. However, high-level athletes are more able to overcome the inertial constraints on action outcomes. They are often stronger and more coordinated, and as a consequence can affect the movement patterns without involving as many other body segments as novices would; this characteristic may make their actions less able to be anticipated and allow them to produce deceptive or disguised anticipation information (Figure 1.5).

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One may question whether inertial properties can be perceived from the motion of actions. Based on the Kinematic Specification of Dynamics principle (Runeson & Frykholm, 1981), it is possible that inertia is perceived through exploitation of the inverse relationship dynamics have with the kinematic information (see also Runeson & Frykholm, 1983). For example, Runeson and Frykholm (1981) showed that the weights of lifted boxes can be readily perceived from point-light displays, demonstrating that the kinematics of the actors lifting the box contained information about the dynamics of the event. Radius of gyration is a plausible biomechanical variable that may provide information about the inertial properties of the action being anticipated. Radius of gyration is defined as “the distance from the axis of rotation to an assumed point where the concentrated total mass of the body would have the same moment of inertia as it does in its original distributed state” (Drillis & Contini, 1966, p. 5). It is specified from the formula , where *k* is the radius of gyration, *I* is the moment of inertia, and *M* is the mass. In one axis of rotation radius of gyration has a real-world position. As the body rotates, and the kinetic chain develops, there are multiple axes from which the body segments rotate, moving in a proximal to distal direction towards the end effector. Therefore, there is increased complexity in the calculation as the movement evolves. The cross-segment rotation in striking and throwing actions would result in the dominant radius of gyration evolving towards the end effector. As is seen in many eye movement studies, point of gaze moves in a proximal to distal direction (e.g. Williams, Janelle, & Davids, 2004). Skilful anticipation may result from accurate perception of how the inertial properties of the end effector are capable of being influenced by the movements of the rest of the body. This information would evolve dynamically in the proximal to distal sequence. The number of body segments used in its determination may result in this information being globally specified. However, less-skilful anticipation may be based on more localised and less accurate perception of the inertia properties or other information sources, such as joint angles and single limb trajectories, being perceived.

Conclusions and future directions

Skilful anticipation of an opponent's action requires dynamic information to be picked up. There remains some uncertainty in regard to whether this information may be picked up from a single cue, is collected sequentially from different cues over time, or is determined from global processing of sources distributed broadly across many parts of the body. Nonetheless, the use of one (local) cue or one dynamic of an action is unlikely to lead to reliable anticipation because of the many ways the same action outcome can be achieved and may not afford anticipation if it occurs in the latter phases of the action, even if it is highly predictive. In fact, relatively little work has been done on exploring the temporal constraints on anticipation. For example, by when might a response need to be initiated in order to achieve a successful motor response? In order to fully understand the role of postural cue and biological motion perception in anticipation, it is necessary to use methodologies that capture whole-body movement and the multiple dynamics influencing the outcome of the action.

Further research is needed to understand the informational role of the components captured by PCA and the relative contribution of the principal and lower-order components to anticipation. It may be the case that skilful anticipation resides in the ability to extract information from the movement-related noise. The use of multiple regression analysis, discriminant function analysis, and independent component analysis may offer further insights into this issue and may be of great value when applied to larger data sets. However, and regardless of one's theoretical preferences, it is evident that all of the methods used to address such questions have strengths and limitations, so no single approach will adequately answer questions relating to the what, where, and how of anticipation. The strengths and weaknesses of the different approaches used in this chapter are summarised in Table 1.1. As a consequence, scientists are strongly encouraged to use a multitude of methods to establish the predictive value of information isolated and understand how this changes over the time course of the action (Williams & Ericsson, 2005).

<COMP: Place Table 1.1 Here>

In recent years, many advances have been made in nonlinear analysis methods to identify information. It may be the case that these advances offer additional insights. Once the predictive value of an information source is established, it is possible to examine experimentally the extent to which this source is exploited during anticipation. A better understanding is needed of the way individuals use information sources and how this develops as a function of skill and experience. More research using longitudinal designs and designs with pre, post, retention and transfer measures taken and with appropriate control and placebo groups would help address these questions. There remains more work to be done in examining which information source is perceived in the presence of multiple information sources that correlate with outcomes to varying degrees and the conditions in which the predictive value of the information source drives information usage (e.g. Smeeton et al., 2013). This understanding will provide insights into the development of anticipation. It is suggested that perceiving how inertial forces evolve over time may be a candidate information variable for reliable anticipation.

In this chapter, we have focussed on the methods employed to identify the visual information underlying skilled anticipation. However, anticipation occurs in a multisensory environment, and the dynamics of sound and the auditory information accompanying actions have been shown to be important in anticipation (Sors et al., 2017). It is apparent that greater insights into skilled anticipation may be gained by exploring how experts use the full range of information available in the environment and not merely vision. It would be interesting to identify the auditory cues underpinning anticipation, how these may interact with visual information, and whether their use changes as a function of different constraints related to the task as well as stressors typically found in sport, such as fatigue and anxiety. Clearly, in visually impaired sports athletes often have to perform with degraded or absent visual information, providing a stark example of how anticipation may be achieved via the multisensory integration between different sources of information. Nonetheless, research focussed on identifying the postural cues and other visual information underpinning anticipation has proved a rich stream of information over the past four decades. A variety of research methods have been employed, spanning the disciplines of psychology and biomechanics, and these have resulted in significantly improved understanding of this hallmark of expertise. The time already spent in this endeavour is testament to the complexity of the task as well as the importance of anticipation in high-performance domains, yet much work is still needed to understand fully how visual information is perceived and how this interacts dynamically with other perceptual or cognitive sources to result in the skilful motor act performed by few but enjoyed by many.

Figure 1.1 Some example frames of video sequences used in the temporal occlusion approach examining anticipation at the penalty kick in soccer. Milliseconds to and from ball-foot contact are indicated at the top. Initial frame to final frame (left to right) of stimulus videos are presented for temporal occlusion conditions. Final frames represent example occlusion points of a kick.

Figure 1.2 Some example frames of video sequences used in the spatial occlusion approach to examine the cues picked up when anticipating the penalty kick in soccer. Milliseconds to and from ball-foot contact are indicated at the top. Initial frame to final frame (left to right) are presented for conditions where the upper body, head, and hip are occluded (top to bottom rows) during the kick.

Figure 1.3 A classical point-light display (right side) image presented next to a stick-figure representation (left side) of the same tennis player stimulus performing a forehand drive shot.

Figure 1.4 The differences in displacement between forehand strokes in tennis identified by PCA (reproduced from Huys et al., 2008). The differences present the root mean square differences in joint trajectories for inside-out and cross-court shots normalised by shot time duration. In the upper row, marker size differences reflect the RMS difference in the shots. In the row below, each panel represents the averaged fifth of the shot for inside-out (black) and cross-court (grey) stick figures.

Figure 1.5 An example simulation of a biomechanical model of the throwing arm. Torso and right arm pictured. Simulated changes in the motion of the arm result from changing the masses of the limb segments and/or the forces acting on them.

Table 1.1 A summary of the methodological approaches used to identify global and local postural cues and information for anticipation.

Methodology	Global information identified	Local information identified	Time-based information available	Critical observations	Example references

Spatial occlusion	Inferred from decrements in performance in comparison to the non-occluded stimuli	Identified from experimental conditions where only one body region is present	No but may be available when used in combination with temporal occlusion	Regions occluded chosen by experimenter	Abernethy and Russell (1984)
	Disrupts the overall dynamics of the action more than neutralisation			Regions identified may be sport/task/individual specific	
				Biomechanical differences between actions not quantified	
				Response times typically not recorded	

Temporal occlusion	Not possible to identify global information	Not possible to identify local information	Critical time windows identified	Time windows occluded chosen by experimenter Provides no results as to where information resides Time windows may be sport/task/individual specific Biomechanical differences between actions not quantified Response times typically not recorded	Farrow et al. (2005)
Combined spatial and temporal occlusion	See spatial occlusion	Possible to identify how information in local body regions	Yes	Susceptible to experimenter basis in the regions and time windows selected, but bias may be reduced by	Abernethy and Zawi (2007)

		changes over time		combining with biomechanical analysis Requires a large number of trials to be examined for reliable data	
Single biomechanical variable	Not possible to identify global information	Yes but may be limited if the local information is distributed more widely	Temporal information possible if tracked over time	Due to the motion of body segments being linked, other adjacent segments may hold information Predictive value may be found when used with logistic regression Potential bias induced by experimenter selection Computer simulation needed	Alder et al. (2014)

				to verify variable as providing information	
Multiple biomechanical variables	Possible to identify predictive value of combined variables via logistic regression, although it is not possible to identify the nature of their relationship	Possible to identify predictive value of local information	Discrete time points needed. Time-based predictive value results from many regressions performed over a number of time points; therefore it may be possible to identify 'what' and 'when' information	Predictive value of variables found and can be compared to accuracy rates in visual perception studies. Computer simulation needed to verify variable as providing information	Lopes et al. (2014)

Principal component analysis	Captures information from distributed body regions but may not identify the information	Local information not identified but possible to neutralise directional differences between action outcomes	Not possible to break components down in time	May capture information but does not specifically identify Resulting stimulus is computer generated Results from analysis unbiased, although data entered into the analysis may be biased Possible to identify common dynamics when used across individuals	Huys et al. (2008)

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