Perception, 2008, volume 37, pages 931 – 948

doi:10.1068/p5340

Expertise and attunement to kinematic constraints

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Received 16 August 2004, in revised form 6 September 2007; published online 30 May 2008

Abstract. Three experiments were undertaken to ascertain the extent to which expertise in natural anticipatory tasks is characterised by superior attunement to the biomechanical (kinematic) constraints of the movement pattern being observed. Twelve world-class and twelve non-expert badminton players were required to predict the depth of an opponent's stroke from either video displays or point-light displays of the opposing player's hitting action. The information available within the displays was manipulated through temporal and/or spatial occlusion. Consistent with predictions that can be derived from the constraint-attunement hypothesis (Vicente and Wang, 1998 *Psychological Review* **105** 33 – 57), experts showed: (i) an unchanged pattern of information pick-up when the display was reduced from video to point-light and only kinematic information was available; (ii) superior information pick-up from kinematic features that non-experts could use; and (iii) attunement to early kinematic information from the lower body to which non-experts were not sensitive. Consistent with predictions that can be derived from a common-coding perspective (Prinz, 1997 *European Journal of Cognitive Psychology* **9** 129 – 154), the anticipation of stroke depth was facilitated more for experts than non-experts when the perceptual display provided linked segment information reminiscent of the cross-segmental torque transfers that occur during expert movement production.

1 Introduction

A number of studies, both of cognitive tasks, such as chess playing, computer programming, medical decision-making, map reading, and mathematical problem-solving, and of perceptual – motor tasks, such as car driving and playing sports, have demonstrated performance component differences between task experts and lesser-skilled individuals. In the perceptual – motor domain, two sets of tasks—tasks measuring memory recall and tasks measuring anticipation capability—most consistently and reliably show performance gradients that are directly related to skill level. In memory-recall tasks experts repeatedly outperform novices and lesser-skilled individuals in their capacity to recall briefly presented domain-specific patterns of information (eg Starkes 1987). This advantage disappears under conditions where the patterns presented are unfamiliar ones from other domains or ones in which the normal structure of the domain is not present, indicating that the advantage relates to the structured encoding of the information within the pattern and not to a generic memory advantage (Chase and Simon 1973). In anticipation tasks the requirement is to use advance information or forward planning to facilitate early responding in time-constrained situations. In predominantly cognitive activities, such as medical decision-making, experts are characterised by superior advance planning (Koedinger and Anderson 1990), whereas in motor tasks, such as playing fast ball sports, experts are characterised by superior ability in anticipating future outcomes from observation of the early movement patterns of their opponents (Abernethy 1990).

Attempts to explain the superior performance of experts on perceptual – motor tasks have varied in the extent to which they have invoked cognitive constructs, such as representations, information processing, and working memory; or more ecological constructs, such as adaptations and affordances, as the basis for explanation (Abernethy et al 1994), although, increasingly, both types of explanatory approach have been characterised by a focus upon the contribution of constraints of one form or another to expertise (eg Davids et al 2005). Salthouse (1991) has described expertise in terms of the strategic circumvention or at least minimisation of inherent nervous system constraints and limitations (eg anticipation is a means of overcoming the inherent latencies associated with reaction time). E J Gibson (1969, 1991) has conceptualised skill acquisition as the process of adaptation to environmental constraints with experience resulting in the learning of the strategy that is most economical for the task. In terms of perceptual learning this involves learning to focus attention on only a minimal set of key features (invariants) that specify, and help predict, the unfolding events of interest.

Vicente and Wang (1998) extended Gibson's ideas to develop a constraint-attunement hypothesis (CAH) in an attempt to explain and predict expertise effects in memory-recall tasks. The CAH predicts that an expert advantage will exist when: (i) the perceptual array of the task contains goal-relevant constraints (domain-specific structure), and (ii) experts are attuned to these constraints. Expert advantage is predicted to be greatest when the constraints are greatest and to be non-existent in situations where either the display is completely random (unconstrained) or attunement does not occur (attention is directed at the wrong feature/s). While not without its critics (eg Ericsson et al 2000), CAH nevertheless has, to date, proved promising in its capability to explain and predict the presence and relative magnitude of expertise effects in memory-recall studies, although, in the interpretation of the memory literature, the description and determination of levels of constraint through the construction of abstraction hierarchies is still somewhat subjective and contentious. The CAH has not yet been systematically examined in relation to expertise effects in dynamic anticipation/forward-reasoning tasks despite the potential for the description of the constraints within these tasks to be made in more concrete, biomechanical terms than is possible for static memory-recall tasks.

In a parallel development, Prinz and associates (eg Prinz 1997; Hommel et al 2001) have formulated the common-coding hypothesis to describe the functional relationship between perception and action in a range of tasks. A key premise of the common-coding hypothesis is that the perception and production of the same action involve the use of a common central code, with the perception of a particular action invoking the same stored representations as those involved in producing the action. The hypothesis is supported both by neural evidence, showing the presence of 'mirror neurons' that discharge equally when a particular action is observed or produced (eg Buccino et al 2004), and behavioural evidence, showing superior prediction of the actions of self compared with others (eg Knoblich and Flach 2001; Repp and Knoblich 2004). From an expertise perspective, the common-coding notion produces the intriguing propositions that expertise in movement production may facilitate the attainment of expertise in movement perception, that perceptual expertise may be a consequence of mental processes simulating the production of the action being observed, and that expert prediction/anticipation of movement may consequently display similar properties and constraints to expert movement execution. Support for some of these propositions comes from a recent fMRI study showing greater mirror-system activity for expert ballet dancers viewing dance routines than unskilled dancers observing the same action (Calvo-Merino et al 2005), and in expert dancers viewing moves from their own motor repertoire compared with moves with which they were familiar but did not perform (Calvo-Merino et al 2006).

In this paper we report three experiments that provide further empirical evidence as to the nature of expertise in dynamic, predictive task environments and permit systematic examination of some of the predictions arising both from the CAH and from notions of common-coding. In all three experiments we use the skill of anticipation in the sport of badminton as a model for examining perceptual expertise and testing the CAH and common-coding notions. We do so because in racquet sports, like badminton, the time constraints of the activity are such that advance pick-up of information from the opponent's hitting action is essential for successful performance; the hitting action is constrained by quantifiable kinematics and expert performance is likely linked to attunement to this kinematic information; and a considerable amount is already known about the nature of expert movement production.

Hitting actions, of the type used in badminton, are governed by reasonably simple biomechanical principles (Elliott 1995). In hitting any stroke, the movement segments involved in the striking action are recruited sequentially, in a systematic proximal-to-distal manner. The striking action characteristically commences with a forward step of the contralateral leg, followed, in turn, by a cascade of movements of the hip and trunk, the upper arm, the forearm, and the hand holding the racquet. This sequence of segmental movements culminates in rapid racquet displacement at the end of the stroke sequence. The major displacement of the racquet occurs in the 80 – 90 ms period immediately before racquet – shuttle contact, and the major displacement of the arm holding the racquet in the earlier time period from around 170 ms to 80 ms before contact. The major displacements of the trunk and lower body occur sequentially earlier again. By having large proximal muscles recruited first, and smaller faster-acting distal muscles recruited later in the action, optimal cross-segmental summation of speeds is possible (Putnam 1991). Expert movement production in overarm throwing and hitting actions of the type used in badminton are characterised not only by a proximal-to-distal evolution of the movement kinematics but also by a greater contribution of proximal segments to the resultant stroke velocity and a greater transfer of intersegmental forces (eg Gowitzke and Waddell 1979; Sakurai and Ohtsuki 2000).

In order to predict successfully where an opponent is about to hit the next stroke in badminton, and to move quickly to the desired interception point to hit a return stroke, it is necessary to predict quickly and accurately not only the direction but also the depth of the opponent's stroke. Variation in stroke depth is typically achieved by the attacking player varying the force applied to the shuttle at impact. Such variation, however subtle, necessitates some changes in the underlying stroke kinetics and, in turn, in the observable stroke kinematics. Obviously, early and heightened sensitivity to these kinematic changes may afford the player an advantage in responding.

In the experiments reported here, we first sought to determine if there are, in fact, any demonstrable differences in the ability of badminton players of different skill levels to predict stroke depth from the evolving kinematics of an opposing player's movement pattern. With such differences established, we then sought to isolate the specific kinematic features to which only the experts are selectively attuned. In the first experiment, we compared anticipatory performance on a typical temporal-occlusion film task (cf Abernethy and Russell 1987) with that on a point-light task displaying only kinematic information. In line with the CAH, we predicted that an expert advantage would exist both when full visual information was present and when the display provided only vision of the essential kinematic information. In the second and third experiments, we manipulated the precise kinematic information that was available to participants by providing tasks in which the kinematics of selected spatial areas of the opponent's movement pattern were either presented in isolation (experiment 2) or progressively added to more proximal joint motions, simulating the segmental linkages as they exist in the natural setting (experiment 3). Skill-related differences in information pick-up in these two experiments were used, in conjunction with observations from experiment 1, to test the prediction that experts are more attuned to the essential kinematic features of the opponent's hitting action than non-experts. In particular, we predicted that experts would be able to pick up more information from the (same) pertinent kinematics and/or would pick-up useable information from particular kinematic features to which the less-skilled were not attuned. In experiment 3 we also examined the prediction, emerging from the common-coding proposition, that the pattern of information pick-up in expert perception would mirror the segmental linkages known to exist in expert movement production. We report here only information in relation to depth prediction as that in relation to the concomitant prediction of direction is reported elsewhere (Abernethy and Zawi 2007).

2 Experiment 1

In the natural setting, and in video/film simulations of the natural setting, the movement patterns of an opposing player provide kinematic information in conjunction with other sources of information. To ascertain if the expert advantage in anticipation in racquet sports like badminton is due specifically to superior attunement to movement kinematics it is necessary to demonstrate the presence of an expert advantage in situations where only kinematic information is available. The simplest means of presenting pure kinematic displays of biological motion is to use point-light displays of the type popularised by Johansson (1973). These displays, which consist simply of disconnected points of light corresponding to the position of key joint centres on the body of the person being observed and/or on objects with which they are interacting, are devoid of all the contour, texture, shape, colour, and general figural cues that exist within pictorial and film displays, but preserve intact the essential kinematic information provided in the movement pattern of the actor. Veridical perception, categorisation, and judgments of actions are possible from such displays providing the displays depict motions that are biomechanically plausible and consistent with the normal constraints on human movement (Kourtzi and Shiffar 1999). With the availability of appropriate conceptual knowledge, observers appear capable of using the information available within point-light displays to make judgments not only about fundamental movement patterns but also about intentionality and emotion (Dittrich 1993; Dittrich and Lea 1994; Dittrich et al 1996).

In this experiment prediction performance was compared directly between film displays of an opposing player's action and point-light displays of the same action. It was hypothesised that, if attunement to essential kinematic information indeed provides the foundation for expert prediction of stroke depth, then: (1) experts should anticipate stroke depth better and pick up relevant information from earlier time periods on a traditional film-based anticipation task than non-experts; (2) any expertise differences evident in the film displays should also be evident in point-light displays that provide only kinematic information; and (3) at least for the experts, the same time periods that characterise information pick-up from film displays should also permit information pick-up when only pure kinematic motion is available.

There is already considerable evidence to support the first proposition from existing studies of anticipation in racquet sports. It has been well established from early temporal occlusion studies of tennis using film (eg Jones and Miles 1978), and more recently video simulations (eg Williams et al 2002), that expert players are better able than non-expert players to predict an opponent's stroke when only vision of pre-impact (advance) information is available. Abernethy and Russell (1987), using three different occlusion periods before, and two after, the point of racquet – shuttle contact in badminton, demonstrated that experts were not only superior at predicting the depth of an opponent's stroke occluded at the point of contact but were also able to pick up usable advance information from earlier in the opponent's action than could novices. While both experts and novices could pick up information to improve prediction in the 83 ms period prior to contact (a period in which the racquet undergoes its major displacement) and a comparable period immediately after contact (a period in which initial flight of the hit shuttle is visible), only the experts were also able to pick up information in the earlier period from 167 – 83 ms before contact (a period in which the arm holding the racquet undergoes its major displacement). The experts in the Abernethy and Russell (1987) study were national-level players, but relatively few were within the top 100 in the world, while the novices had no badminton experience whatsoever—competitive or recreational. This leaves unclear the extent to which a more elite group of experts might display an even more pronounced pattern of early information pick-up and, perhaps more importantly, the extent to which a control group with some (but not high-level) badminton playing experience might show a sensitivity to advance information comparable to that seen with experts.

There is only limited evidence available to date in relation to the second and third propositions, and what is available is equivocal. Abernethy et al (2001) demonstrated that the same time periods that characterise pick-up of directional and depth information by expert and novice squash players viewing video displays also hold true when they view point-light displays. Ward et al (2002) showed that experienced tennis players outperform inexperienced players in anticipating shot direction from both normal and point-light displays, whereas, in contrast, Shim et al (2005) found that an expert advantage in anticipating shot direction that was evident in a video display was not reproduced in a point-light display. In the prediction of stroke direction in badminton the same basic patterns of information pick-up were preserved for film and point-light displays (Abernethy and Zawi 2007), but it was unclear whether this would be reproduced for depth predictions.

2.1 *Methods*

2.1.1 *Participants.* Twelve expert and twelve non-expert male badminton players participated voluntarily in this and all subsequent experiments. The experts were selected from a pool of players and coaches in the Malaysian national badminton training squad. At the time of testing all of the players were ranked within the top 100 in the world and all coaches had previously held rankings as players within the top 20 in the world. The non-experts were undergraduate physical-education students from the University Putra Malaysia. All possessed basic badminton skills, had played badminton at a recreational but not at a competitive level, and had seen international level badminton matches played.

2.1.2 *Procedures.* The participants were individually administered the original film-based temporal-occlusion task of Abernethy and Russell (1987) and a point-light version of the same task. The original task was constructed by filming, from the on-court viewing position of an opposing player, 32 different badminton strokes executed by a provincial-level male badminton player. Each of these strokes was then shown to the participants under five different levels of temporal occlusion with the order of presentation of the total of 160 trials (32 strokes $\times$ 5 occlusion levels) randomised. The occlusion conditions were 167 ms prior to racquet – shuttle contact (t_1), 83 ms prior to contact (t_2), the point of contact (t_3), 83 ms after contact (t_4), and after all outward flight of the shuttle was completed (t_5). [See Abernethy and Russell (1987, figure 1, page 329) for examples of the occlusions.] Successive trials were separated by an inter-trial interval (ITI) of 5 s.

The point-light task was created by first digitising, from the film task, the spatial coordinates of each of the major joint centres of the opponent's body plus the shuttle and key landmarks on the racquet. Digitising was performed with a Calcomp digitiser, and for each frame of the film task a total of 26 spatial coordinates were determined. These coordinates depicted the spatial location of the vertex of the head, the chin – neck intercept, right and left shoulder, elbow, wrist, middle knuckle, hip, knee, ankle, heel, and toe, together with the position of the shuttle and the handle, neck, sides, and head of the racquet. Each of these coordinates was then simply displayed as a white centroid against a black background and its motion animated in real time with customised software. As is typical of other point-light displays, the display was ambiguous when stationary but was immediately recognisable as a badminton player by all participants once the display was in motion. Aside from the use of point-light representations, the constructed task was in all other aspects identical to the film task.

Both the film and the point-light tasks were shown to the participants on a large-screen monitor. Within each task, the participants were required to make judgments immediately after viewing each trial whether the stroke they were seeing was a smash shot going long or a drop shot going short (a depth judgment), and whether the direction of the stroke was cross-court or down the line, although only the depth judgments are reported here. Participants recorded their predictions by circling their chosen option on a standardised response sheet. Each task took some 20 min to complete with a 60 s rest interval given after the completion of each block of 80 trials. Half of the participants completed the film task first and half the point-light task first.

2.1.3 *Analysis of data.* Two main analyses were undertaken and used in tandem to examine information pick-up. First, the percentage errors in predicting stroke depth were calculated for each participant, arcsine transformed, and then subjected to a 3-way analysis of variance. This ANOVA was used to examine the main and interactive effects of the factors of skill level, display type (film or point-light), and time of occlusion, with particular interest, within each display type, in the comparison between the prediction error of the expert and non-expert groups at each of the occlusion conditions and in the within-group comparison of prediction error across adjacent temporal-occlusion conditions. In the event of any violation of sphericity, a Greenhouse–Geisser correction was applied to the degrees of freedom. Partial eta-squared (η_p^2) values were computed to determine the proportion of total variability attributable to each factor or set of factors, and the origins of any significant effects were sought by the Tukey HSD procedure. Second, the 95% confidence limits were calculated for prediction error for each skill group at each occlusion condition under each display condition and used to determine if the prediction performance differed significantly from that which could have arisen simply from guessing. A prediction error significantly less than 50% was necessary for a conclusion of information pick-up to be sustained.

In addition to the two main analyses, two 3-way (group × condition × occlusion) ANOVAs were conducted to test for possible presentation-order effects. One analysis, to test for possible carryover benefits from the prior film task exposure, compared the prediction performance on the point-light task between those participants who had undertaken the film task beforehand and those who had not, while a second analysis was used to determine if prior exposure to the point-light task had any influence on prediction accuracy on the film task.

2.2 *Results*

Figure 1 shows error in predicting stroke depth as a function of skill level, display type, and occlusion level. A significant main effect was obtained for skill ($F_{1,22} = 31.05$, $p < 0.01$, $\eta_p^2 = 0.59$), with the experts systematically outperforming the non-experts. Skill level did not interact significantly with either the occlusion ($F_{2.64,58.13} = 2.71$, $p > 0.05$, $\eta_p^2 = 0.11$) or display ($F_{1,22} = 0.24$, $p > 0.05$, $\eta_p^2 = 0.01$) factors. The three-way (skill × display type × occlusion) interaction was also nonsignificant ($F_{2.39,52.46} = 1.72$, $p < 0.05$, $\eta_p^2 = 0.07$). Significant main effects were obtained for both display type ($F_{1,22} = 12.20$, $p < 0.01$, $\eta_p^2 = 0.36$) and occlusion ($F_{2.64,58.13} = 80.66$, $p < 0.01$, $\eta_p^2 = 0.79$) but these effects were overridden by a significant interaction between these two factors ($F_{2.38,52.46} = 4.226$, $p < 0.05$, $\eta_p^2 = 0.16$). Prediction performance was poorer on the point-light task than on the film task for the three occlusion conditions without

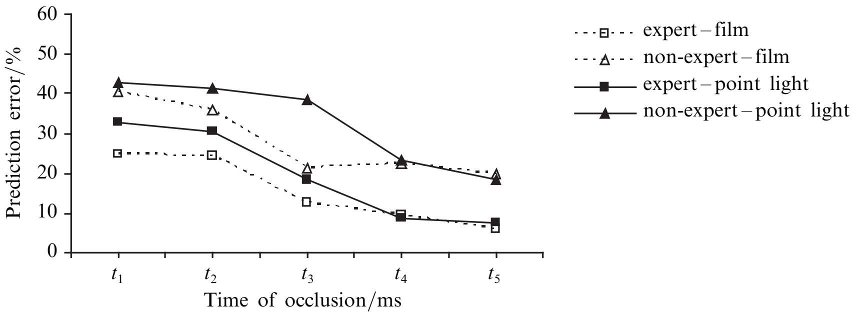

Figure 1. Error in predicting stroke depth for expert and non-expert players for the video and point-light displays used in experiment 1. All errors are significantly superior to the 50% guessing level.

shuttle flight (t_1, t_2, and t_3) but indistinguishable for the post-contact conditions (t_4 and t_5). Predictions of stroke depth were significantly superior to chance/guessing levels for both skill groups under both display conditions at all occlusion levels. This suggested that both experts and non-experts were able to pick up useful advance information as early as the period prior to t_1 and regardless of whether the display was feature-rich film or simply kinematic motion. Both groups also significantly reduced their prediction error from t_2 to t_3 under both display conditions, suggesting that information available prior to t_1 and in the $t_2 - t_3$ time window may be most critical for the advance prediction of stroke depth.

The analyses conducted to compare the influence of prior exposure to either the film or point-light task failed to reveal any evidence of carryover effects. Participants who did the point-light task second, having first experienced the film task, were no different in their performance on the point-light task to those without prior film-task experience. The performance of the groups with and without prior film-task experience was indistinguishable overall ($F_{1,20} = 0.03$, $p > 0.05$) and prior film-task experience also did not interact significantly with either the skill level ($F_{1,20} = 2.95$, $p > 0.05$) or occlusion factors ($F_{4,80} = 0.06$, $p > 0.05$). Similarly, the analysis comparing performance on the film task of participants who had earlier undertaken the point-light task with those who had not revealed neither a main effect for prior point-light task experience ($F_{1,20} = 1.85$, $p > 0.05$) nor a significant interaction of this factor with skill level ($F_{1,20} = 3.99$, $p > 0.05$) or time of occlusion ($F_{4,80} = 1.23$, $p > 0.05$).

2.3 *Discussion*

The evidence obtained in relation to the first hypothesis (that experts, on the video task, would anticipate stroke force better and would pick up relevant information from earlier time periods than non-experts) was mixed. The experts were clearly able to anticipate stroke force in a superior manner to the less-skilled players, significantly outperforming them in terms of prediction accuracy at each occlusion point in the video task. The experts' ability to extract more information from the same time windows was particularly evident for the period up to t_1, in which their prediction error was well below guessing levels ($M = 25.00\%$, SD $= 5.96\%$), whereas that of the non-experts approached guessing levels ($M = 40.62\%$, SD $= 5.33\%$). There was little or no evidence, however, of the type that has been apparent in some earlier studies (and typically manifest in the form of a significant group $\times$ occlusion interaction) to indicate earlier information pick-up by the expert group. For the film task, the pick-up of advance information by both the experts and non-experts appeared to occur in the same two time periods—prior to t_1 and from t_2 to t_3.

Supportive evidence was obtained from experiment 1 in relation to the second hypothesis (that any expertise differences evident in the video displays would also be evident in the point-light displays containing only kinematic information). A skill main effect was obtained that did not interact with display type. In the film task, the experts maintained an average prediction advantage of some 12.6% across all occlusion conditions and this advantage was maintained, and even marginally increased to 13.2%, under the point-light conditions.

The third hypothesis (that the same time periods that characterise information pick-up from video display would also permit information pick-up in the point-light displays) was also supported in experiment 1, at least in relation to the pre-contact ($t_1 - t_3$) occlusion periods. For both skill groups there was evidence of advance information pick-up prior to t_1 and in the $t_2 - t_3$ period, but not from $t_1 - t_2$, and this finding was consistent regardless of whether the display was film or point-light. This indicates that expert–non-expert differences in anticipatory performance are fundamentally a consequence of differences in the pick-up of information from kinematic, rather than non-kinematic, sources. This is consistent with the CAH in that the expert advantage persists within the display that is purely kinematic because the goal-relevant constraints for the task are also kinematic.

The time periods revealed for information pick-up in this experiment were somewhat different from those observed by Abernethy and Russell (1987). While Abernethy and Russell also found $t_2 - t_3$ information pick-up by both their experts and novices, they additionally found evidence for information pick-up in the $t_1 - t_2$ period for the experts. The methodology they employed (with a continuous rather than discrete depth judgment) did not permit determination of information pick-up in the pre-t_1 period and this makes comparisons to the current findings difficult. More-direct means of determining attunement to specific sources of kinematic segmental information are needed to further understand the likely sources of differences in the apparent time course of information pick-up between this experiment and the one conducted by Abernethy and Russell (1987). In experiment 2 we attempt such a determination.

3 Experiment 2

While experiment 1 provided evidence to demonstrate systematic differences in the capability of players of different skill levels to use kinematic information to anticipate the depth of an opponent's stroke, it did not permit direct determination of the specific kinematic information that was used by the expert and non-expert players to make these predictions. By inference, segments undergoing their major displacement during the pre-t_1 period (viz the trunk and lower body) and in the $t_2 - t_3$ period (viz the racquet) are prime candidates as sources of anticipatory information but their actual usage requires experimental confirmation. The possibility cannot be precluded from experiment 1 of information pick-up occurring from sources, such as arm motion in the $t_1 - t_2$ period, but with this information pick-up being redundant with that available from other, earlier-occurring sources.

The purpose of experiment 2, therefore, was to identify the specific kinematic information used by the players of different skill levels, and to ascertain whether the expert players used the same information sources as non-experts (but in a superior manner), or rather were able to pick up selective information from kinematic sources to which the less-skilled were not attuned at all. We sought to determine what information expert and non-expert players could pick-up when only the kinematics of selected segments was presented within the point-light displays. It was hypothesised, on the basis of findings from the point-light task in experiment 1, that both expert and non-expert predictions of stroke depth would be characterised by a capability to pick up useful information from both the kinematics of the racquet in isolation (in the $t_2 - t_3$ period) and the kinematics of the trunk and/or lower body (in the period prior to t_1). This prediction stands in contrast to the earlier findings of Abernethy and

Russell (1987) who, in a second experiment using a paradigm in which visibility to specific cues within a film display was selectively masked, found that the defining characteristic of the expert group in the prediction of stroke force/depth was reliance on advance information from the motion of the arm holding the racquet. Neither skill group in this earlier study appeared to rely on the trunk or lower body for unique advance information about stroke force.

3.1 *Methods*

3.1.1 *Procedures.* In this experiment, participants viewed point-light displays similar to those used in experiment 1 with the exception that, instead of all 26 key joint, racquet, and shuttle coordinates, a much smaller subset of coordinates was displayed. There were four different point-light displays in all, each of which presented motion of the shuttle but shared no other display points in common. In addition to the motion of the shuttle, condition 1 also displayed motion of the racquet, condition 2 motion of the arm holding the racquet, condition 3 motion of the upper body (but excluding the arm holding the racquet), and condition 4 motion of the lower body. The same five temporal-occlusion conditions, the same specific strokes, and the same response requirements as used in the previous experiment were again used in this experiment with the order of presentation of the four conditions counterbalanced across participants and skill groups. Operationally this meant that one participant was assigned to each of the 24 possible presentation orders and that equal numbers of experts and non-experts were presented each condition first.

3.1.2 *Analysis of data.* We sought evidence of advance information pick-up from each condition within the specific time period in which the displayed feature underwent its maximal change in displacement. For condition 1 (the racquet) this involved examining changes in prediction accuracy across the $t_2 - t_3$ period; for condition 2 (the arm holding the racquet) the interest was in the $t_1 - t_2$ period; and for conditions 3 (upper body) and 4 (lower body) the focus was upon prediction performance up to t_1. A series of eight planned comparisons were conducted (see table 1 for details) and the outcomes from these were used, in conjunction with comparisons of the prediction accuracy levels against the 50% guessing level, to determine if information pick-up from the four different displays had occurred during the expected time periods. Evidence for information pick-up was sought in the form of prediction error at the end of the time

Table 1. Planned comparisons for prediction of force in experiment 2.

Comparison	df	t	p	d
Condition 1 [Racquet + shuttle]				
t_2 versus t_3 for experts	11	5.65	0.00**	*2.41*
t_2 versus t_3 for non-experts	11	0.88	0.20	0.37
experts versus non-experts at t_3	22	4.71	0.00**	*2.00*
Condition 2 [Arm + shuttle)				
t_1 versus t_2 for experts	11	0.95	0.18	0.48
t_1 versus t_2 for non-experts	11	1.44	0.09	0.46
experts versus non-experts at t_2	22	1.63	0.06	0.69
Condition 3 [Upper body + shuttle]				
experts versus non-experts at t_1	22	2.03	0.03*	*1.12*
Condition 4 [Lower body + shuttle]				
experts versus non-experts at t_1	22	2.36	0.01*	*1.18*

Note: One-tailed t-tests are reported given that all comparisons involve a priori predictions of the direction of differences between means. $^{*}p < 0.05$, $^{**}p < 0.01$. Large effect sizes ($d > 0.80$) are italicised to aid identification.

window of interest being superior to chance and prediction error significantly reducing from the start of the time window to the end. Where possible, direct skill-group comparisons were also made at the end of the time window to determine if any information pick-up that occurred across the particular time window, or any of its predecessors, was sufficient to provide an expert advantage. The planned comparisons were conducted on the depth-error data following arcsine transformation and were restricted to only those time windows providing advance information, thus excluding analysis of occlusion conditions t_4 and t_5. Cohen's d statistic was also calculated to measure the effect sizes for the planned comparisons.

3.2 *Results*

The errors in predicting stroke depth in experiment 2 are presented in figure 2 and the results of the planned comparisons in table 1.

Experts (figure 2a) were able to pick up information about stroke depth from the kinematics of the racquet in isolation (condition 1) as evidenced by a significant reduction in error from t_2 to t_3 and an error level at t_3, but not at either t_1 or t_2, that was significantly superior to chance. No comparable information pick-up from the isolated kinematic motion of the racquet was apparent for the non-experts (figure 2b), resulting in a significant expert advantage at t_3 for condition 1. In contrast, while there was visual evidence of an improvement in prediction accuracy in $t_2 - t_3$ for the experts when only arm kinematics were visible, the experts, like the non-experts, showed no evidence of information pick-up from the arm during the period $(t_1 - t_2)$ in which it

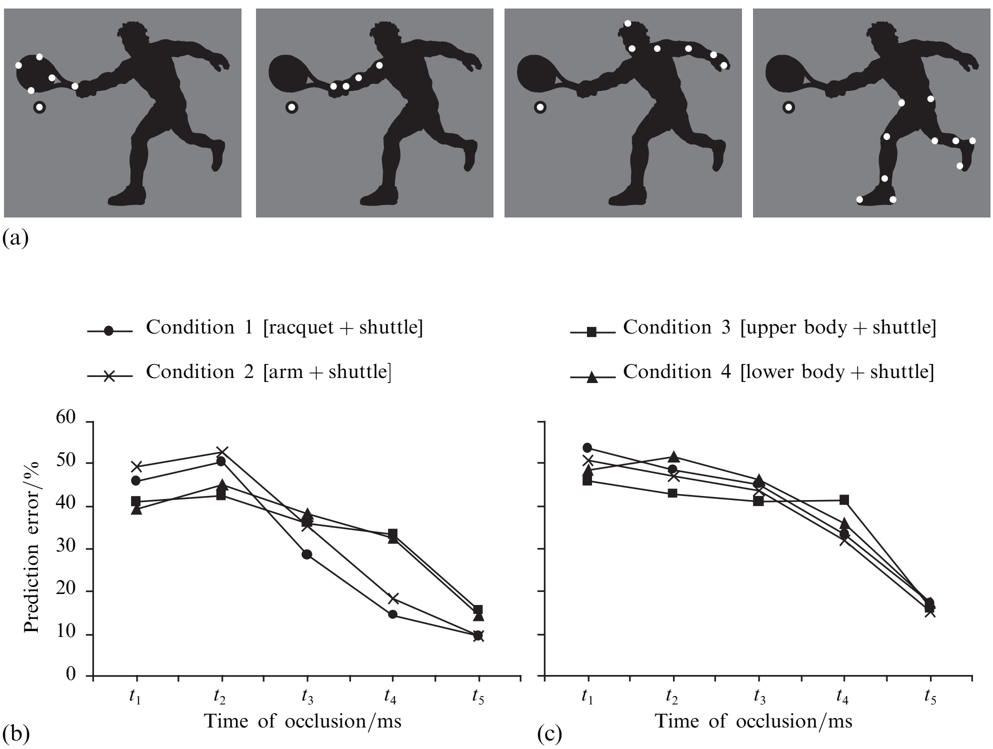

Figure 2. Error in predicting stroke depth (b) for expert and (c) non-expert players under the four point-light display conditions (a) used in experiment 2. For the experts errors at all occlusions for conditions 3 and 4 and at $t_3 - t_5$ for conditions 1 and 2 are significantly superior to the 50% guessing level. For the non-expert players errors at all occlusions for condition 3 and at $t_3 - t_5$ for conditions 1 and 2 and $t_4 - t_5$ for condition 4 are significantly superior to the 50% guessing level.

underwent its major displacement. For both the upper-body and the lower-body kinematics (conditions 3 and 4 respectively) error at t_1 and all subsequent occlusion times was significantly superior to chance for the expert group. This indicates that the experts were indeed able to pick up advance information from both the kinematics of the upper body (exclusive of the playing-side arm and racquet) and the kinematics of the lower body to aid in the prediction of stroke depth, and that this information pick-up occurs at some time prior to 167 ms before racquet–shuttle contact (t_1). For the non-experts, only prediction accuracy in condition 3 (upper body kinematics) was significantly superior to chance at t_1, suggesting attunement to upper-body but not lower-body kinematics. In both instances, the prediction accuracy achieved by the experts at t_1 on the basis of isolated upper-body and isolated lower-body kinematics was significantly superior to that achieved by the non-experts.

3.3 *Discussion*

The obtained results were consistent with the predictions derived from experiment 1 for the experts but not for the non-experts. For the experts, clear evidence was found of their capability to pick up and use information available from the isolated kinematics of the racquet, the upper body, and the lower body during the time periods that these segments underwent their major changes in displacement and made their major contribution to the hitting action. For the non-experts, however, the only evidence of information pick-up from the kinematic segments was from the upper body prior to t_1. Counter to the hypotheses generated from experiment 1, the non-experts were unable to pick up information from either the racquet or the lower body when the kinematics of these segments was presented in isolation from the segments to which they are usually linked.

These differences in the capability to pick up information from the kinematics of isolated segments also resulted in a significant expert advantage in prediction of depth being apparent for the racquet (condition 1 at t_3), the upper body (condition 3 at t_1), and the lower body (condition 4 at t_1), but not the arm holding the racquet (condition 2 at t_2). Consequently, in this experiment the experts demonstrated not only a capability to pick up more information from the same sources of kinematic information used by lesser-skilled players but also a capability to pick up information from some specific segments (viz the early-occurring lower body kinematics and the later-occurring racquet kinematics) to which the lesser-skilled players were apparently not attuned.

The specific conclusions from this experiment with respect to information pick-up from different display features differ in a number of ways from those reached by Abernethy and Russell (1987) on the basis of their spatial-occlusion experiment. In the Abernethy and Russell study, the arm holding the racquet emerged as the key cue for expert anticipation of stroke depth and the lower-body information and the trunk did not emerge as useful. The more elite expert group used in this sample may well account for the apparent use of lower-body kinematic information by the experts in this study. However, it is also important to note that the procedures adopted in this experiment to determine the locus of information for stroke prediction differed in a number of important ways from the spatial-occlusion approach used by Abernethy and Russell (1987). The present experiment provided only kinematic information (via point-light displays), whereas the earlier experiment used feature-rich film information. In the present experiment we also asked a fundamentally different question: in particular, we asked how much information was carried, in isolation, by each kinematic feature, whereas, with their spatial occlusion methodology, Abernethy and Russell asked, instead, how much information was lost when a specific spatial region of the display was masked. In the spatial-occlusion technique other areas of the display could potentially provide compensatory or alternative information when a specific area was masked; in the stand-alone approach in this experiment there was no other information available.

4 Experiment 3

Experiment 2 provided evidence with respect to how much information was provided by selected kinematic features of the opponent's display, when only these features were seen, and how attunement to this information varied as a function of the skill level of the observer. What the approach adopted in experiment 2 does not reveal is how much information each key segmental feature provides when other linked segmental features are also visible, as they are in the natural setting. Consequently, the purpose of experiment 3 was to determine what additional information can be provided by selected segments when their kinematics are added to the kinematics of existing segments.

Understanding expert – non-expert differences in information pick-up under conditions where segments are linked may be potentially important with respect to the common-coding hypothesis (Hommel et al 2001). The skilled production of overarm hitting patterns is characterised by the summation and transfer of torques across linked segments with the more skilled performers recruiting and making greater use of larger, proximal segments (such as the lower body and trunk) than do less-skilled performers (Gowitzke and Waddell 1979). If the successful prediction of movement indeed involves common neural processes and pathways to those involved in movement production, then it might be hypothesised that the expert players, with their greater repertoire of movement-production experience involving inter-segmental coordination, may be more able to utilise linked segment information for prediction than less-skilled players, whose own movement production more likely involves primarily distal segments such as the arm holding the racquet.

In experiment 3 we sought to determine if the addition of vision of more proximally linked segments would help enhance the pick-up of information of use in anticipating stroke depth and, if any such facilitation occurred, whether it was selectively greater for the expert performers. Three specific questions were examined for both the expert and non-expert players. (1) Is prediction of stroke depth based on the kinematics of the racquet enhanced if the kinematics of the arm holding the racquet are also visible? (2) Is depth prediction based on the kinematics of the arm and racquet enhanced if the kinematics of the upper body is also visible? (3) Is depth prediction based on the kinematics of the upper body, arm, and racquet enhanced if the kinematics of the lower body is also visible?

4.1 *Method*

4.1.1 *Procedures.* The same participants and general experimental procedures were used as in the previous experiments but some different point-light display conditions were added. The four different point-light displays compared in this experiment were: the racquet + shuttle (condition 1; as in experiment 2); the arm + racquet + shuttle (condition 2); the upper body + arm + racquet + shuttle (condition 3); and the lower body + upper body + arm + racquet + shuttle (condition 4; as in experiment 1). These conditions, illustrated in figure 3, were selected so as to provide a spectrum of display information approximating the proximal-to-distal addition of segments that occurs within the normal hitting action in badminton and other racquet sports. The order of presentation of the two new conditions undertaken by the participants was counter-balanced. Equal numbers of participants from each skill group experienced condition 2 first as experienced condition 3 first.

4.1.2 *Analysis of data.* A series of planned comparisons was used to assess the additive contribution of the different kinematic features to anticipation of stroke depth with these comparisons conducted on the percentage prediction errors following arcsine transformation. Prediction errors under conditions 1 and 2 were compared at t_3 to determine if vision of the arm segment (visible only in condition 2) added significantly to the prediction accuracy that was possible from vision of the kinematics of the racquet alone (condition 1). Conditions 2 and 3 were compared at t_2 to determine if vision of the upper body added to the prediction accuracy that was possible from vision of the kinematics of the racquet and arm alone. Conditions 3 and 4 were compared at t_1 to determine if vision of the kinematics of the lower body added to the prediction accuracy that was possible from vision of only the upper body kinematics. As in the previous experiment the planned comparisons were restricted to only those time windows in which the segment of interest had undergone maximal changes in displacement. In order to conclude that the addition of the kinematics of the more proximal segment provided information to the participants above and beyond that available from vision of only the more distal segment, a significantly lower error was required for the condition with the proximal segment added. The analyses were again restricted to the pre-contact occlusion conditions only (ie t_1, t_2, and t_3).

4.2 *Results*

The errors in predicting stroke depth are presented in figure 3 and the results of the planned comparisons are presented in table 2.

Conditions 1 and 2 were not significantly different at t_3 for the experts (figure 3b) but were for the non-experts (figure 3c), indicating that for the non-experts, but not the experts, contemporaneous vision of the arm improved the accuracy of depth predictions beyond that which was achievable on the basis of observing only racquet kinematics. However, despite the improved prediction accuracy by the non-experts with the additional availability of arm information, the prediction accuracy of the non-experts when viewing both the arm and racquet was still significantly poorer than that of the experts.

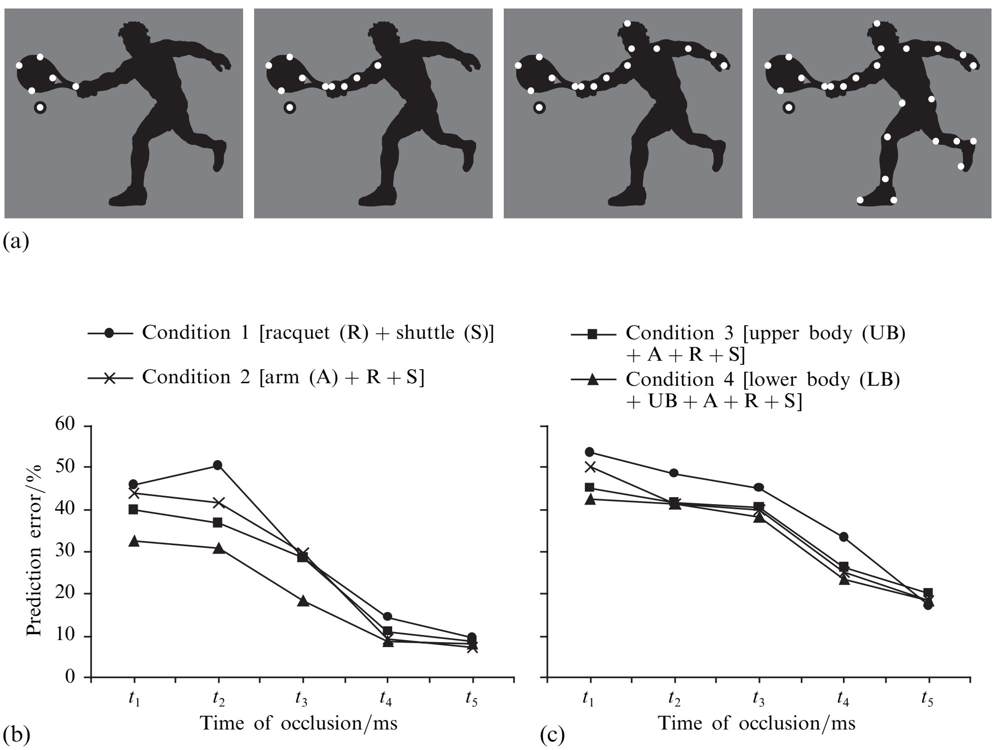

Figure 3. Error in predicting stroke depth (b) for expert and (c) non-expert players under the four point-light display conditions (a) used in experiment 3. For the expert players all points are significantly superior to guessing levels except for t_1 and t_2 for condition 1 and t_1 for condition 2. Similarly, for the non-experts all points are significantly superior to guessing levels except for t_1 and t_2 for condition 1 and t_1 for condition 2.

Table 2. Planned comparisons for prediction of force in experiment 3.

Comparison	df	t	p	d
Conditions 1 and 2				
condition 2 versus condition 1 at t_3 for experts	11	0.52	0.31	0.19
condition 2 versus condition 1 at t_3 for non-experts	11	2.62	0.01*	0.53
experts versus non-experts at t_3 for condition 2	22	2.72	0.01**	*1.03*
Conditions 2 and 3				
condition 3 versus condition 2 at t_2 for experts	11	2.16	0.03*	0.51
condition 3 versus condition 2 at t_2 for non-experts	11	0.18	0.43	0.04
experts versus non-experts at t_2 for condition 3	22	1.61	0.06	*0.84*
Conditions 3 and 4				
condition 4 versus condition 3 at t_1 for experts	11	2.57	0.01*	*1.11*
condition 4 versus condition 3 at t_1 for non-experts	11	0.97	0.18	0.31

Note: One-tailed *t*-tests are reported given that all comparisons involve a priori predictions of the direction of differences between means. * $p < 0.05$, ** $p < 0.01$. Large effect sizes ($d > 0.80$) are italicised to aid identification.

The comparison of conditions 2 and 3 at t_2 revealed the reverse statistical findings. Viewing the kinematics of the upper body improved prediction accuracy beyond that achievable from racquet and arm kinematics for the experts but not for the non-experts. The comparison of the two skill groups under condition 3 at t_2 just failed to obtain statistical significance in favour of the expert group, although the effect size for the comparison was large. Finally comparison of conditions 3 and 4 at t_1 revealed clear evidence that the additional vision of lower body kinematics (in condition 4) was beneficial to the experts but not for the non-experts. For the experts, either the lower body provides unique information or its simultaneous presence acts as some form of reference to facilitate information extraction from the upper body, arm, or racquet.

4.3 *Discussion*

Experiment 3 provides mixed evidence with respect to the benefits of linked segment information for prediction of stroke depth. For the experts, the concurrent presence of the arm segment provided no additional information to that available from the isolated kinematics of the racquet, indicating that whatever information the arm kinematics may provide (and experiment 2 suggests this is minimal) is redundant with that available from the racquet. For the non-experts, however, the arm segment does appear to provide useful referential information for the racquet, although, even with this facilitation, prediction accuracy for the arm and racquet complex is still poorer for the non-experts than for the experts. In contrast to the situation with the arm segment, the addition of linked information from the upper body (to the arm and racquet) and the lower body (to the upper body, arm, and racquet) is beneficial in enhancing the prediction accuracy of the experts but not the non-experts. The upper-body and lower-body information, shown to be useful in isolation for the experts in experiment 2, is therefore not redundant with respect to that available later from more distal segments. For the non-experts, however, the upper body, shown to be useful in isolation in experiment 2, is apparently redundant as a source of information with the arm and racquet—the concurrent presence of the upper body not enhancing depth prediction accuracy for the non-experts.

In broad agreement with the propositions derived from the common coding hypothesis, experts appear to benefit most, in terms of depth prediction accuracy, from the contemporaneous presence of segmental information linked in a way that is compatible with natural movement production. Interestingly, this observation with respect to the anticipation of stroke depth is the converse of findings with respect to the prediction of stroke direction for the same group of participants (Abernethy and Zawi 2007). A possible cause of these differences is that prediction of stroke depth requires a prediction of contact force, which in turn is primarily a product of cross-segment summation of forces, whereas directional changes can be invoked by more local segmental changes (such as simply varying the degree of forearm pronation – supination) at the point of impact. Production and prediction of stroke depth may therefore be more likely to benefit from inter-segmental linkage than the production and prediction of stroke direction.

5 General discussion

The collective evidence from the three experiments indicates systematic differences in regard to the information sources to which players of different levels of expertise are attuned. While experiment 1 revealed that both experts and non-experts were able to pick up information in the period prior to t_1 (ie prior to 167 ms before racquet – shuttle contact) and in the $t_2 - t_3$ time window (the 83 ms leading up to racquet – shuttle contact), experiments 2 and 3 demonstrated clear skill-related differences in attunement to the specific kinematic features undergoing change during these critical time periods.

For the experts, information pick-up prior to t_1 appeared to be attributable to attunement to the kinematics of both the upper body (excluding the playing-side arm and racquet) and the lower body. Both these segments provided information in isolation (as revealed by experiment 2) and the information each provided in linkage to more proximal segments was also not redundant. Vision of the linked upper-body kinematics improved predictions based on the arm and racquet, and vision of the linked lower-body kinematics improved predictions based on the upper body, arm, and racquet (experiment 3). For the non-experts, what information pick-up occurred prior to t_1 appeared attributable simply to sensitivity to the isolated kinematics of the upper body (experiment 2). No evidence was forthcoming for the non-experts of the ability to use the earlier-occurring lower-body kinematics, with prediction based on the lower body alone being no better than chance (experiment 2), and the addition of the lower body bringing no improvement in depth predictions beyond that achievable from the upper body, arm, and racquet (experiment 3).

The information pick-up in the period from $t_2 - t_3$ in experiment 1 by the experts was apparently due to their attunement to information contained specifically within the racquet kinematics. Experiment 2 demonstrated pick-up of depth information by the experts from the displays containing only isolated racquet kinematics, while there was no accompanying evidence of pick-up of useful depth information from the arm segment, either when the segment was presented alone (experiment 2) or contemporaneously with the racquet (experiment 3). In contrast, the pick-up of information in the $t_2 - t_3$ period by non-experts (experiment 1) appeared dependent upon the simultaneous presence of the arm and the racquet. The non-experts failed to show any capability to predict stroke depth at better than chance levels when either the racquet or arm were present in isolation (in experiment 2) although the concurrent presence of the arm permitted a significant improvement in prediction from the racquet kinematics and permitted prediction accuracy to become better than chance levels. While, for the non-experts, the arm appeared to provide beneficial referential information for the racquet, it is noteworthy that even this facilitation was insufficient to bring the prediction accuracy of the non-experts to a level approaching that of the experts.

The findings differ in some important ways from previous studies of anticipatory prediction of depth by badminton players of different skill levels. In particular, they differ from those of Abernethy and Russell (1987) in implicating both the upper body and lower body, but not the playing-side arm, as potent sources of advance information for experts.

The evidence of sensitivity to the earlier-occurring upper-body and lower-body information among expert badminton players is new (cf Abernethy and Russell 1987) and is likely a consequence of the use of higher-calibre players and more-direct investigative methodologies in the present study. The capacity of the expert players in this study to extract this early upper-body and lower-body information reduces the functional importance to these players of sensitivity to (the later occurring) arm information.

The findings in relation to depth prediction also show differences from those in relation to direction prediction obtained from the same cohort of participants (cf Abernethy and Zawi 2007). While advance direction prediction is like advance depth prediction in that both skill groups rely primarily on the pre-t_1 and $t_2 - t_3$ time windows for information pick-up, the specific sources of this information are quite different. First, with respect to isolated kinematics, depth information is available from a wider range of sources than is directional information. Whereas directional information is only available from the racquet and lower body in isolation (and only for the experts), depth information is also available from the upper body (and for both skill groups). Second, linked segmental information appears to be more beneficial for the experts for the advance prediction of stroke depth than direction. As noted previously, this is most likely because stroke direction may be altered simply at the level of a single local segment (eg through alteration in the degree of forearm pronation) and can therefore be detected without reliance on inter-segmental information whereas alteration of the impact forces determining stroke depth may require modulation of torque transfers occurring across multiple, linked segments.

The evidence collected across the three experiments permits empirical assessment of predictions that can be derived from some current theoretical propositions about expert performance and the coding of information for perception and action. The majority of the collected evidence was consistent with predictions that can be made from the constraints-attunement hypothesis of Vicente and Wang (1998). Experiment 1 revealed that, for both experts and non-experts, the pick-up of essential task information is attributable to attunement to the biomechanics of the movement pattern being viewed, with the same temporal pattern of information pick-up emerging regardless of whether the viewed display contained all usual visual cues or only kinematic information. Experiments 2 and 3 revealed that experts have a greater attunement to essential kinematic features in the biomechanics of the opponent's hitting action than do non-experts. The experts showed a clear capability to utilise, if necessary, information arising from the isolated kinematics of the racquet, the upper body, and the lower body, whereas the non-experts showed this capability only for the upper-body kinematics. Not only do non-experts appear incapable of picking up the same amount of information as experts when viewing the same kinematic features, but there are also clearly some features (the lower body in particular) to which only the experts appear attuned. The selective attunement of experts to lower-body kinematics may be especially important given that this affords the experts the functional advantage of an earlier start to active pick-up of anticipatory information and, as a consequence, to the planning and initiation of an appropriate movement response. Experts were demonstrably more perceptually sensitive to the biomechanical factors that constrain the force of the opponent's hitting action in the badminton anticipation task, thereby lending general support to Vicente and Wang's (1998, page 48) contention that "... one of the hallmarks of expertise is attunement to goal-relevant constraints". The findings from experiment 3 were also in broad agreement with propositions from the common-coding perspective that movement prediction involves common coding and many common processes to those underpinning movement production. The availability of linked segment information, depicting the biomechanics of the hitting action and reminiscent of the linkage that occurs in expert movement production, facilitated the perceptual performance of the experts more than of the non-experts.

While the experiments conducted here demonstrate that experts have the capability to utilise kinematic information in a superior manner to non-experts, it is important to acknowledge that this does not necessarily mean that experts normally attend to, or choose to use, such information. Determining what information experts actually use, as opposed to have the capability to use, is challenging methodologically. One possible means of indirectly assessing this issue and, at the same time, determining the practical value of information about skill-related differences in information pick-up, is to ascertain if the anticipatory and playing performance of non-experts can be made more expert-like through selective exposure to kinematic information, such as in the form of point-light displays. There is little direct empirical evidence available at this time to assess the efficacy of using point-light displays to train anticipatory skill although there is some evidence from observational learning studies (eg Horn et al 2005) to suggest that point-light displays may aid skill learning under certain circumstances. A major challenge for the acquisition of all forms of perceptual–motor expertise, especially that which occurs in time-constrained tasks, is that many of the critical aspects of perception may be best acquired and controlled implicitly, and conscious attention to critical cues may be counterproductive (Jackson and Farrow 2005).

Determining the task constraints and the nature of expertise-related differences in the pick-up of information about these constraints provides a valuable step toward ascertaining what must be learned in order to become an expert on a particular task. Understanding how that learning occurs, and how the acquisition of perceptual expertise might best be facilitated through practice and instruction, presents the next obvious and considerable challenge. While demonstrably important, anticipatory skill is only one component of many that are critical to successful performance in activities like racquet sports. For learners and players of intermediate skill the enhancement of anticipatory skill likely presents a necessary, but not in itself sufficient, condition to satisfy on the pathway to expert performance.

Acknowledgments. This work was partially supported by a grant from the Research Grants Council of Hong Kong Special Administrative Region, China (Project No. HKU7400/05H). Appreciation is extended to two anonymous reviewers for helpful comments and suggestions on an earlier version of this manuscript.

References

Abernethy B, 1990 "Expertise, visual search and information pick-up in squash" *Perception* **19** 63–77

Abernethy B, Burgess-Limerick R J, Parks S, 1994 "Contrasting approaches to the study of motor expertise" *Quest* **46** 186–198

Abernethy B, Gill D, Parks S L, Packer S T, 2001 "Expertise and the perception of kinematic and situational probability information" *Perception* **30** 233–252

Abernethy B, Russell D G, 1987 "Expert–novice differences in an applied selective attention task" *Journal of Sport Psychology* **9** 326–345

Abernethy B, Zawi K, 2007 "Pick-up of essential kinematics underpins expert perception of movement patterns" *Journal of Motor Behavior* **39** 353–367

Buccino G, Binkofski F, Riggio L, 2004 "The mirror neuron system and action recognition" *Brain and Language* **89** 370–376

Calvo-Merino B, Glaser D E, Grèzes J, Passingham R E, Haggard P, 2005 "Action observation and acquired motor skills: an fMRI study with expert dancers" *Cerebral Cortex* **15** 1243–1249

Calvo-Merino B, Grèzes J, Glaser D E, Passingham R E, Haggard P, 2006 "Seeing or doing? Influence of visual and motor familiarity in action observation" *Current Biology* **16** 1905–1910

Chase W G, Simon H A, 1973 "The mind's eye in chess", in *Visual Information Processing* Ed. W G Chase (New York: Academic Press) pp 215–282

Davids K, Renshaw I, Glazier P, 2005 "Movement models from sport reveal fundamental insights into coordination processes" *Exercise and Sport Sciences Reviews* **33** 36–42

Dittrich W H, 1993 "Action categories and the perception of biological motion" *Perception* **22** 15 – 22
Dittrich W H, Lea S E G, 1994 "Visual perception of intentional motion" *Perception* **23** 253 – 268
Dittrich W H, Troscianko T, Lea S E, Morgan D, 1996 "Perception of emotion from dynamic point-light displays represented in dance" *Perception* **25** 727 – 738
Elliott B C, 1995 "The biomechanics of tennis stroke production", in *Science and Racket Sports* Ed. T Reilly (London: Spon) pp 89 – 97
Ericsson K A, Patel A, Kintsch W, 2000 "How experts' adaptations to representative task demands account for the expertise effect in memory recall: Comment on Vicente and Wang (1998)" *Psychological Review* **107** 578 – 592
Gibson E J, 1969 *Principles of Perceptual Learning and Development* (New York: Appleton-Century-Crofts)
Gibson E J, 1991 *An Odyssey in Learning and Perception* (Cambridge, MA: MIT Press)
Gowitzke B A, Waddell D B, 1979 "Qualitative analysis of the badminton forehand smash as performed by international players", in *Proceedings of a National Symposium on Racquet Sports* (Chicago, IL: University of Illinois) pp 10 – 25
Hommel B, Musseler J, Aschersleben G, Prinz W, 2001 "The Theory of Event Coding (TEC): a framework for perception and action planning" *Behavioral and Brain Sciences* **24** 849 – 878
Horn R R, Williams A M, Scott M A, Hodges N J, 2005 "Visual search and coordination changes in response to video and point-light demonstrations without KR" *Journal of Motor Behavior* **37** 265 – 274
Jackson R C, Farrow D, 2005 "Implicit perceptual training: how, when, and why?" *Human Movement Science* **24** 308 – 325
Johansson G, 1973 "Visual perception of biological motion and a model for its analysis" *Perception & Psychophysics* **14** 201 – 211
Jones C M, Miles T R, 1978 "Use of advance cues in predicting the flight of a lawn tennis ball" *Journal of Human Movement Studies* **4** 231 – 235
Knoblich G, Flach R, 2001 "Predicting the effects of actions: interactions of perception and action" *Psychological Science* **12** 467 – 472
Koedinger K R, Anderson J R, 1990 "Abstract planning and perceptual chunks" *Cognitive Science* **14** 511 – 550
Kourtzi Z, Shiffar M, 1999 "Dynamic representations of human body movement" *Perception* **28** 49 – 62
Prinz W, 1997 "Perception and action planning" *European Journal of Cognitive Psychology* **9** 129 – 154
Putnam C, 1991 "A segment interaction analysis of proximal-to-distal sequential segment motion patterns" *Medicine and Science in Sports and Exercise* **23** 130 – 144
Repp B H, Knoblich G, 2004 "Perceiving action identity: how pianists recognize their own performances" *Psychological Science* **15** 604 – 609
Sakurai S, Ohtsuki T, 2000 "Muscle activity and accuracy of performance of the smash stroke in badminton with reference to skill and practice" *Journal of Sports Sciences* **18** 901 – 914
Salthouse T A, 1991 "Expertise as the circumvention of human processing limitations", in *Toward a General Theory of Expertise: Prospects and Limits* Eds K A Ericsson, J Smith (Cambridge: Cambridge University Press) pp 286 – 300
Shim J, Carlton L G, Chow J W, Chae W S, 2005 "The use of anticipatory visual cues by highly skilled tennis players" *Journal of Motor Behavior* **37** 164 – 175
Starkes J L, 1987 "Skill in field hockey: The nature of the cognitive advantage" *Journal of Sport Psychology* **9** 146 – 160
Vicente K J, Wang J H, 1998 "An ecological theory of expertise effects in memory recall" *Psychological Review* **105** 33 – 57
Ward P, Williams A M, Bennett S J, 2002 "Visual search and biological motion perception in tennis" *Research Quarterly for Exercise and Sport* **73** 107 – 112
Williams A M, Ward P, Knowles J M, Smeeton N J, 2002 "Anticipation skill in a real-world task: Measurement, training and transfer in tennis" *Journal of Experimental Psychology: Applied* **8** 259 – 270

ISSN 0301-0066 (print) ISSN 1468-4233 (electronic)

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VOLUME 37 2008

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