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Do expertise and the degree of perception – action coupling affect natural anticipatory performance?

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Abstract. Two experiments using a temporal occlusion paradigm (the first with expert and novice participants and the second with participants of intermediate skill) were conducted to examine the capability of tennis players to predict the direction of an opponent's service in situ. In both experiments two different response conditions, reflecting differing degrees of perception – action coupling, were employed. In a coupled condition players were required to make a movement-based response identical to that which they would use to hit a return of service in a game situation, whereas in an uncoupled condition a verbal prediction of service direction was required. Experiment 1 provided clear evidence of superior prediction accuracy under the coupled response condition when ball flight was available, plus some limited evidence to suggest that superior prediction accuracy under uncoupled response conditions might hold true if only advance (pre-contact) information was available. Experiment 2 showed the former finding to be a robust one, but was unable to reveal any support for the latter. Experiment 1 also revealed that expert superiority is more apparent for predictions made under natural (coupled) than uncoupled response-mode conditions. Collectively, these findings suggest that different perceptual processes may be in operation in anticipatory tasks which depend on skill level, the type of information presented, and degree of perception – action coupling inherent in the task requirements.

1 Introduction

A major methodological issue in all areas of exercise and sport science research is the balance struck in experimental work between the replication of the natural world [what Neisser (1976) termed *ecological validity*] and the imposition of tight experimental control or *rigour*. In the study of human motor expertise the historical bias has been toward rigour at the expense of ecological validity. The predominant influence of an information-processing or cognitive-science perspective on expertise research has, more often than not, resulted in the use of experimental conditions in which either simple movement responses are required to complex stimuli, or the converse. Partitioning perception and action in this way may be convenient experimentally but problematic with respect to ecological validity. In essence, it removes the essential coupling of perception and action that is inherent in the performance of the task of interest in situ (Gibson 1979). Moreover, such an approach may be counterproductive when examining motor expertise, as close reproduction of the characteristics of the natural task may be important to the demonstration of expertise effects and hence to any attempt to determine experimentally the underlying source of the expert's advantage (Abernethy et al 1993).

The theoretical importance of preserving natural perception – action couplings to understanding skilled perception and action has been argued most persuasively by Gibson (1979). Gibson noted that perception and action are functionally interdependent, and any experimental approach that manipulates one may unintentionally alter the other. A number of studies have provided strong experimental evidence in support of Gibson's position. For example, in the domain of coincidence timing, Bootsma

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and colleagues (Bootsma 1989; Bootsma and van Wieringen 1990) have demonstrated that the timing-precision characteristic of expert interceptive performance is possible only through continuous functional linkages between perceptual information and movement-control parameters. Likewise, von Hofsten (1987) has drawn attention to the greater precision of interceptive actions that is possible in (apparently complex) natural actions (such as reaching, grasping, and catching) compared with (apparently simpler) actions of the type required to make coincidence-timing judgments in a laboratory setting. Collectively, these observations are consistent with the presence of dedicated, specialised neural processors for the control of natural actions, such as interception. These processors may have evolved through millions of years of natural selection [given that both engineering and avoiding collisions in the natural world would be an important element of natural selection (Abernethy and Burgess-Limerick 1992; von Hofsten 1987)] but can be only fully and effectively used in natural tasks of the type for which they evolved (Runeson 1977).

Neurophysiological support for the importance of maintaining the normal coupling of perception and action when examining perceptual-motor skill can also be gleaned from the work of Milner and Goodale (1995). They argue that two functionally different neural mechanisms are involved in the programming of a visuo-perceptual motor response. It is suggested that the 'vision for perception' ventral stream delivers information about the characteristics of objects and their relations for the purpose of perceptual identification and classification. In contrast, the 'vision for action' dorsal stream mediates the on-line visual control of selected actions (Goodale and Haffenden 1998). When these two functional streams of visual processing are considered in relation to the experimental issue of perception – action coupling it becomes apparent that it is possible that much of the previous uncoupled laboratory-based research may have tapped only into the ventral stream of processing, whereas natural perception – action coupled tasks would require the contribution of both streams.

A particular focus of motor-expertise research over the past decades has been the examination of the respective capability of expert and lesser-skilled ball-sport players to pick up information from the movement patterns of opponents, specifically information from the kinematics of the opponent's movement patterns that precede the availability of ball-flight information (eg Abernethy et al 2001). This interest has arisen through attempts to explain the phenomenological impression that experts in fast ball sports present as "having all the time in the world". While a little is known about the importance of natural perception – action couplings in preserving highly skilled interception of moving balls, what is completely unclear at this time is whether the degree of perception – action coupling has any systematic impact on the capability to pick up earlier (advance) information from the complex kinematics of the opponent's movement patterns. The mediating effect a performer's skill level may have on perceptual accuracy within different perception – action coupled response modes has not been specifically investigated.

While there has not been any direct study of perception – action coupling, recent research on perception in natural settings nevertheless allows some insight into the perceptual processes operating in tasks with differing degrees of perception – action coupling. The advent of liquid-crystal occluding spectacles (Milgram 1987) has provided researchers with an opportunity to examine the information sources (both movement pattern and ball flight) used by experts and novices in interceptive actions in the natural performance environment. Additionally, this research has allowed comparisons to be made with similar previous research completed in an uncoupled laboratory-based setting.

Starkes et al (1995) used liquid-crystal spectacles in the natural setting to examine expert and novice volleyball players' predictions of the landing location of a volleyball serve at a number of time points pre-service and post-service ball contact.

Findings were similar to previous laboratory-based research (eg Wright et al 1990) in demonstrating the expert's superiority at service prediction. Despite the use of an on-court setting, predictions were done statically in the Starkes et al study rather than through a coupled movement response. Abernethy et al (2001) occluded vision at a range of times before and after contact while squash players were involved in on-court simulated match play. In order to maintain natural perception – action coupling, players were required to continue to move and attempt to play their next shot despite visual occlusion. Results again revealed commonality with the traditional laboratory tests of temporal occlusion in that expert players were superior in both prediction of stroke direction and depth across the majority of the occlusion times examined (Abernethy and Russell 1987).

An interesting observation from the studies with the liquid-crystal occluding technology is that despite enhanced ecological validity, the results have continued to mirror the findings of the previous uncoupled, laboratory-based motor-expertise work (eg Abernethy and Russell 1987; Wright et al 1990). This suggests that perhaps the same perceptual processes may be used by performers in the field setting as in the laboratory, despite differences in the display characteristics and response methods used. However, as noted previously, an important omission from these studies is that they have not directly compared prediction and response accuracy between conditions where perception and action are tightly coupled and the, more typical, laboratory context where perception and action are uncoupled. Therefore, although the results of the newer field-based studies typically support the conclusions about expert advantage, derived from earlier laboratory studies, it remains unclear whether the extent of the expert superiority may be accentuated (or diminished) if the response mode is made to be more typical of that required within the natural setting.

Two experiments are reported here that address these issues. In the first experiment, a progressive temporal occlusion paradigm was applied in the natural setting to examine expert – novice differences in predicting the direction of an opponent's service in tennis. Both pre-contact kinematic information from the opponent's service action and post-contact ball-flight information were presented to the players, who were then required to make predictive judgments under two different response conditions reflecting differing degrees of perception – action coupling. The primary purpose was to determine whether the extent to which perception and action are naturally coupled influences predictive performance, and whether this depends in any way on the type of information (pre-contact versus post-contact) that is available for the prediction. A secondary purpose was to examine whether the relative predictive accuracy under coupled-versus-uncoupled situations was mediated at all by skill level. In the second experiment the same experimental protocol was repeated with intermediately skilled participants. The purpose of this second experiment was to provide confirmatory information on the relationship between advance and ball-flight information and the type of response condition (coupled or uncoupled).

2 Experiment 1

2.1 *Method*

2.1.1 *Participants.* Sixteen tennis players participated voluntarily in this experiment. Eight were classified as experts and consisted of members of either the elite Australian Institute of Sport tennis programme, Queensland Academy of Sport tennis programme, or were open-aged nationally ranked competitors. This group had an average age of 17.5 years and had played tennis for an average of 9 years. The eight members of the novice group were drawn from the undergraduate student population at The University of Queensland. Their mean age was 19.6 years and they had played tennis for an average of 5.8 years.

2.1.2 *Apparatus.* Testing was conducted on a regulation Rebound Ace™ outdoor tennis court. Participants wore a pair of PLATO liquid-crystal spectacles (Milgram 1987) to control visual occlusion and industrial-strength earmuffs to negate any auditory information that may have been used as a source of anticipatory information. The spectacles could either be made transparent to permit vision, or opaque to occlude vision. The switching from transparent to opaque was controlled within a 3 ms period via the activation of a computer and UHF transmitter interface unit controlled manually by the experimenter. This unit was connected to a UHF receiver worn in a carry-pack strapped to the player's back at waist level. The radio frequency emitted from the transmitter unit concurrently triggered the spectacles to occlude, and a light-emitting diode (LED) to illuminate, within the field of view of a 'NAC' HVRB-200 high-speed video camera. The camera operated at 200 Hz and was positioned behind the receiving player. The camera image provided a synchronised record of the following key features of the serve–return scenario: (1) moment of LED illumination (which equates to occlusion onset); (2) service kinematics; (3) moment of racquet–ball contact for the server; (4) service direction; and (5) receiver movement direction and shot selection. Subsequent inspection of the video footage enabled the time of visual occlusion and racquet–ball contact to be recorded to within ± 10 ms and an objective classification of the receiver's prediction accuracy relative to service direction to be made for each trial.

2.1.3 *Procedure.* All participants were required to respond to tennis serves hit by two different right-handed male servers representative of an intermediate level of tennis skill and unfamiliar to the participants. After a 5 min warm up session to familiarise themselves with the servers, participants were fitted with the occlusion spectacles and earmuffs and were given 10 pre-test practice trials. The purpose of these pre-test trials was to familiarise the participants with the task requirements.

Two different response conditions were used to examine the impact of differing degrees of perception–action coupling on the player's prediction of service direction. The coupled condition required players to make a movement response identical to that which they would use to return in a game situation. In the uncoupled condition, a verbal prediction of whether service was directed to their forehand or backhand side was required. This response was to be made immediately after any temporal occlusion occurred. Participants commenced each trial from a position at the intersection of the baseline and singles sideline—a position corresponding with the typical receiver's position in tennis. The uncoupled response required the participants to remain standing in this position for the duration of the trial whereas in the coupled condition the players were specifically instructed to attempt to hit a successful return stroke.

Irrespective of the response condition, all trials commenced with introductory vision-of-service preparation that included the server walking up to the baseline, assuming the service stance, and bouncing the ball. This introductory phase was simply provided so that participants had an orientation to the general service situation and were therefore ready to respond. Through the use of a progressive temporal occlusion approach (see figure 1), five different temporal occlusion conditions were presented for each response condition. The occlusion conditions were selected so as to provide viewing windows into different features within the servers' movement patterns, specifically separating pre-contact information from ball-flight information. As is evident in figure 1, in condition t1 the display was occluded 900 ms prior to racquet–ball contact (or earlier) at a point corresponding with the commencement of the ball toss. In condition t2 occlusion occurred 600 ms prior to racquet–ball contact (or earlier) at the point where the ball toss had nearly reached its zenith. In addition to the information visible at t1, t2 also provided vision of the upward movement of the ball toss and the racquet's movement into a 'Y' position with the ball-toss hand. In condition t3

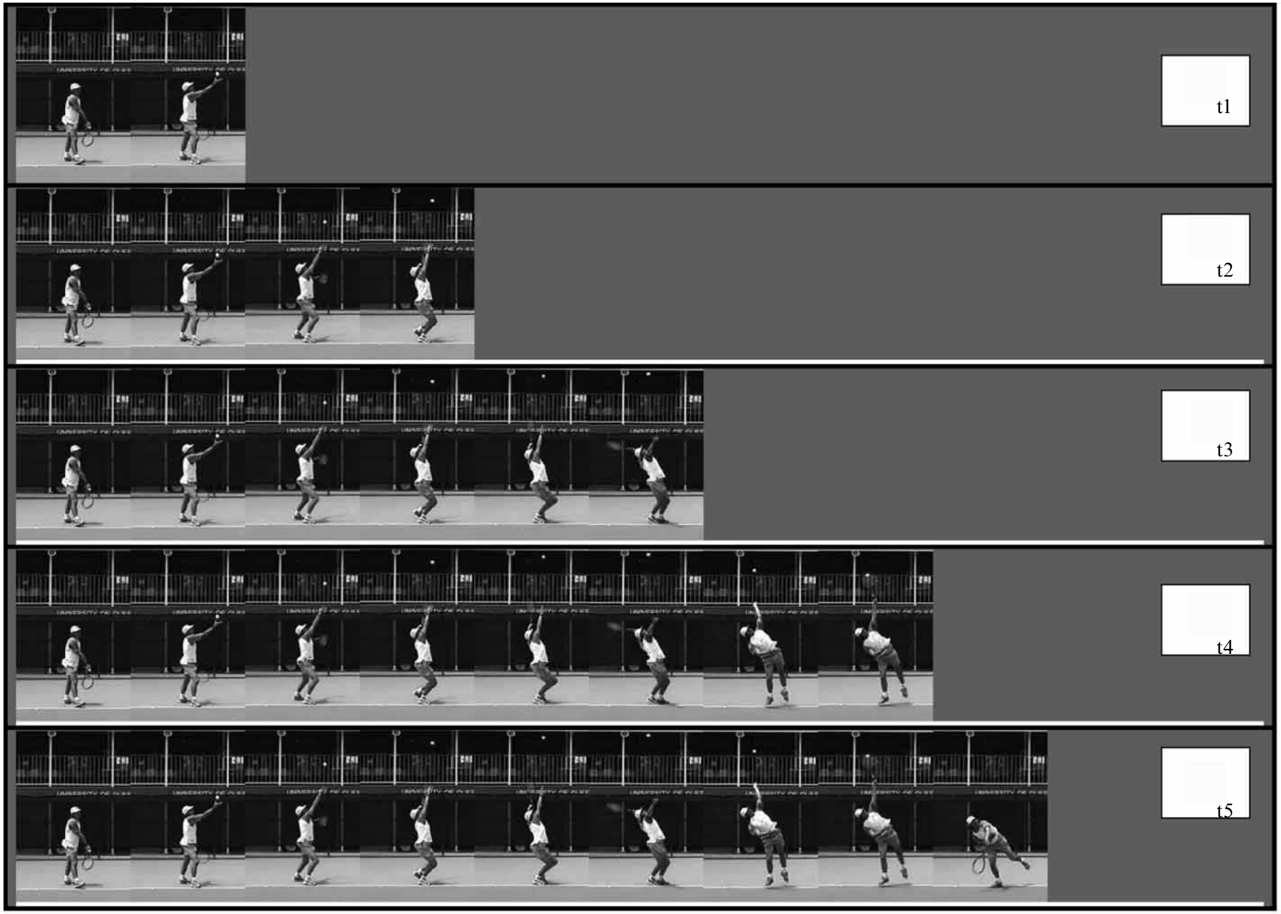

Figure 1. A schematic representation of the five successive 300 ms occlusion conditions imposed during the traditional progressive temporal occlusion method.

occlusion occurred when the racquet was at the top of the back-swing and the ball toss hovering at its zenith at a time 300 ms prior to contact (or earlier). This condition presented, in addition to vision of the information available in t2, vision of the server's action, including the movement of the racquet head toward the start of the back-swing. In condition t4 the display around the point of racquet – ball contact was occluded and consequently the participant could see, in addition to what was presented in t3, the back-swing into the 'back-scratch' position, the acceleration or throwing of the racquet head up to the ball, and any final downward movement of the ball toss. In condition t5 the display at a point after contact was occluded, permitting vision of the server's follow-through motion plus, importantly, post-contact movement of the ball until it reached the vicinity of the net.

All participants received a total of 120 serves in their testing session (60 trials in the coupled condition and 60 in the uncoupled condition), with each of these serves hit at speeds of approximately 80 km h^{-1}. The servers followed a predetermined random schedule identical for each participant, to distribute the serves as equally as possible to the left and right sides of the service box. Serves that were hit into the middle of the service box were eliminated from analysis, as it was deemed too difficult to objectively classify a player's response to such serves. Furthermore, on those occasions where participants did not move either to the left or right, an incorrect response was recorded. Each server would complete all required serves for one response condition before the second server commenced his trial block of the same response condition. The same procedure was then followed for the other response condition. Response conditions (coupled or uncoupled) were therefore blocked for each participant but the order of presentation of the response conditions and servers was counterbalanced across participants.

2.1.4 *Occlusion-condition sampling.* The manual control of the liquid-crystal spectacles does not allow precise trial-to-trial occlusion onset. As a result, subsequent video inspection of the trials was necessary to sort the data into the five 300 ms time conditions relative to racquet – ball contact. A possible confound, as a result of this process, is that the subsequent inspection determined means within each 300 ms occlusion condition which may not have been evenly distributed between the groups. For example, although the performances of both groups are based on the sampling of means within the same 300 ms occlusion condition (eg the t4 condition), actual mean occlusion point for that condition for one group may be 10 ms before contact, providing them with significantly more visual information than another group whose mean may be at 290 ms before contact.

To check against sampling bias, a $2 \times 2 \times 5$ (skill level $\times$ response condition $\times$ temporal occlusion condition) ANOVA with repeated measures was completed. The dependent measure in this analysis were the exact occlusion times, within each of the five 300 ms occlusion conditions, experienced by each skill group. Results revealed that after the subsequent sorting procedure had been completed, the mean occlusion times experienced by each skill level were essentially equal. The mean number of test trials remaining for each skill group at each occlusion condition following the subsequent sorting procedure was also subjected to the same three-way ANOVA. Again, it was found that the number of trials included for analysis for each group was sufficiently evenly distributed between conditions so as to make possible the main comparisons planned for the study.[1]

[1] The statistical data for these comparisons and those presented in experiment 2 can be obtained by contacting the first author.

2.1.5 *Analysis of data.* Responses in the coupled condition were defined as the final direction (left or right) that the participants moved their body in an attempt to intercept the oncoming serve. The uncoupled responses were recorded as left (verbalised as backhand by a right-handed player) or right (verbalised as forehand by a right-handed player). The percentage of successful responses under each response condition for each time window was then calculated. The advantage of this measure was that it could provide direct comparison between occlusion and response conditions.

The accuracy data for these participants were analysed with a $2 \times 2 \times 5$ (skill level $\times$ response condition $\times$ temporal occlusion condition) factorial ANOVA, with repeated measures on the last two factors. In keeping with the primary purpose of the study, key points of comparison were the examination of differences between the coupled and uncoupled response conditions, and examination whether this comparison was affected by the time when the display was occluded (or, in other words, what information was available to support the prediction). Also of interest was the between-groups comparison of the prediction accuracy of the experts and novices for each response condition at each of the occlusion points.

2.2 *Results and discussion*

2.2.1 *Response mode effects.* While there was no overall main effect for response mode ($F_{1,14} = 0.05$, $p > 0.05$) the type of perception – action coupling used did interact significantly both with the time of occlusion and with the skill level of the participants. The interaction between the response condition and the time of occlusion ($F_{4,56} = 9.34$, $p < 0.05$) indicated that the relative prediction accuracy under the coupled and uncoupled response conditions varied according to the information sources available to the players (see figure 2).

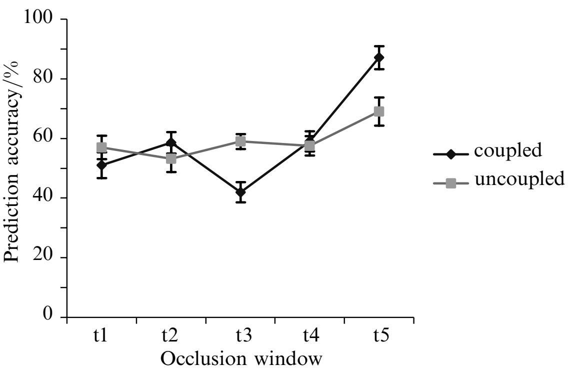

Figure 2. Prediction accuracy as a function of the occlusion window and response condition for experiment 1. Error bars represent standard errors.

The uncoupled response at the pre-contact occlusion period of t3 was significantly more accurate than the coupled response at the same time point ($t_{15} = -5.64$, $p < 0.05$). The root cause of this appears to be a surprising drop in prediction accuracy for the coupled response condition (taking it significantly below chance), rather than a significant improvement in the prediction accuracy for the uncoupled response condition. What is not clear from the current data is whether this interaction between pre-contact information sources at t3 and the uncoupled response condition is a robust finding with theoretical significance, or rather merely a spurious observation unique to this particular data set. This issue is addressed in greater detail in experiment 2.

While the prediction accuracy for both coupled and uncoupled response conditions was superior to chance at the t5 occlusion condition, the coupled response mode produced a significantly higher prediction success at this post-contact occlusion period than occurred for the uncoupled response condition ($t_{15} = 4.34$, $p < 0.05$). The interaction between coupling mode and time of occlusion was comparable for both skill groups, there being no higher-level three-way interaction between skill level, response mode, and occlusion conditions ($F_{4,56} = 0.10$, $p > 0.05$). The critical observation, therefore, is that, when ball-flight information was available, higher prediction accuracy was observed for the coupled rather than the uncoupled response condition. A reasonable interpretation of this finding is that the perception and prediction of ball-flight information may be handed through a dedicated processor, evolved over millions of years, that is only capable of being used fully and effectively in the natural context of coupled actions. In contrast, in the absence of ball flight (ie conditions t1 – t4, in which only pre-contact movement-pattern information was available), minimal differences were evident in the prediction accuracy under coupled and uncoupled response conditions. Superior perceptual accuracy was found for the uncoupled response at one of the four pre-contact occlusion conditions t3 but this appeared to be due largely to the poorer than chance performance under the coupled response mode rather than any facilitated performance in the uncoupled response mode.

2.2.2 *Expertise effects.* Table 1 shows the mean prediction accuracy for the expert and novice groups for each response condition at each occlusion window. The prediction accuracy of the expert group was superior to chance levels at conditions t2, t4, and t5 in the coupled response condition and t3, t4, and t5 in the uncoupled response condition. In contrast, the prediction accuracy for the novice group was superior to chance levels at condition t5 (for both the coupled and the uncoupled response conditions) and was slightly inferior to chance levels at t3 in the coupled response condition.

Table 1. Prediction accuracy means (with standard deviations) for expert and novice participants in the coupled and uncoupled response conditions for each occlusion window.

Response condition	Occlusion window				
	t1	t2	t3	t4	t5
Coupled					
experts	56.22 (14.64)	67.44* (9.62)	46.22 (13.99)	66.81* (12.47)	90.50* (8.32)
novices	45.75 (19.66)	49.64 (17.89)	37.69** (13.51)	51.23 (14.70)	83.70* (20.09)
Uncoupled					
experts	57.43 (18.60)	59.18 (17.46)	61.18* (6.97)	60.00* (13.11)	69.13* (19.08)
novices	56.55 (12.41)	47.19 (18.82)	56.74 (12.27)	55.09 (12.74)	68.85* (18.78)

* Significantly above chance levels of 50% ($p < 0.05$)
** Significantly below chance levels of 50% ($p < 0.05$)

An ANOVA revealed a significant main effect for skill level, with the experts, predictably, being more accurate than the novices ($F_{1,14} = 5.76$, $p < 0.05$); however, this was moderated by a significant higher-order interaction between the response condition and the skill level of the participants ($F_{1,14} = 5.12$, $p < 0.05$). As figure 3 reveals, expertise effects on prediction accuracy were clearly evident under the coupled, but not the uncoupled, response condition. The superior performance of the experts under this condition, where the natural coupling of perception and action was preserved, was due to both a mean increase in accuracy for the expert group and a mean decrease in accuracy for the novice group—relative to their performance in the uncoupled condition. This interaction between response mode and skill level is not mediated by the time of occlusion variable; there being, as noted earlier, no significant higher-order interaction between these three variables.

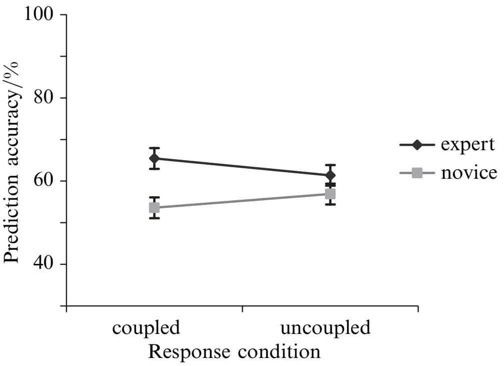

Figure 3. Prediction accuracy as a function of the response condition and level of expertise. Error bars represent standard errors.

Expert participants displayed perceptual accuracy significantly above chance levels in the coupled response condition (mean = 65.44%) and significantly superior to that of the novices. Unlike experts, novice prediction performance was not significantly different from chance levels (mean = 53.60%). No such expertise effects were observed for the uncoupled response mode. The absence in this study of an expert advantage in the uncoupled conditions may well occur because the uncoupled conditions deny experts access to the dedicated perceptual processes that are fundamental to their expertise, but rather present simplified task demands that are (relatively) advantageous to novices. Both the experts' and the novices' prediction performances were significantly above chance levels within the uncoupled response condition (experts = 61.38%, novices = 56.89%). Collectively, these findings illustrate the potential for couplings, other than those that are the usual functional ones, to underestimate the expert capability and overestimate the novice capability.

3 Experiment 2

Experiment 1 suggests a clear prediction superiority of coupled responses over uncoupled responses when ball-flight information is available (t5). The evidence from experiment 1 with respect to the relative accuracy of coupled versus uncoupled responses, when the prediction must be based only on pre-flight cues, was less clear. There was some suggestion that the uncoupled condition may produce superior prediction accuracy, but this was based entirely on the observation at one of the four advance occlusion conditions (t3), in which the effect was produced by an unexpected decreased in prediction accuracy under the coupled condition rather than any increased prediction accuracy under the uncoupled condition. The purpose of experiment 2 was to gather additional data from a different skill group to see, generally, whether the interaction between response mode and prediction accuracy, evident in experiment 1, was reproducible and specifically whether the low prediction accuracy evident at t3 in experiment 1 was a random or reproducible observation.

3.1 *Method*

3.1.1 *Participants.* Thirty-two tennis players participated voluntarily in this experiment. All players were classified as intermediately skilled junior players based on their local club and school rankings. The participants had an average age of 15 years and had played tennis for an average of 4.7 years. These players formed part of a larger study of perceptual learning (see Farrow and Abernethy 2002). We report here the pre-test results for this group as they provide some insight into issues of pertinence to the current study.

3.1.2 *Apparatus and procedure.* In this experiment, we employed exactly the same apparatus and experimental procedure as in experiment 1.

3.1.3 *Occlusion-condition sampling.* As in experiment 1, statistical checks were conducted on subsequently determined means within each 300 ms occlusion condition and the mean number of test trials included for analysis after the subsequent sorting procedure. On this occasion it was only necessary to determine whether the two response conditions could be considered equivalent. Results revealed that both response conditions had occlusion-condition means that were indistinguishable and these were based on a similar amount of experimental trials (see footnote 1).

3.1.4 *Analysis of data.* The same data-analysis procedure was employed as in experiment 1. The only exception was that, with only one group of participants, the skill level of the participants was not a factor in the analyses. Hence, the accuracy data were analysed with a 2×5 (response condition $\times$ temporal occlusion condition) fully repeated-measures ANOVA. As previously, the key points of comparison were the examination of differences between the coupled and uncoupled response conditions and examination whether this comparison was mediated in any way by the time-of-occlusion factor. Of particular interest was whether the same significant occlusion $\times$ response condition difference, evident at the t3 and t5 occlusion windows in experiment 1, would also be evident for this sample of players.

3.2 *Results and discussion*

As had been the case in experiment 1, there was no overall main effect for response mode ($F_{1,31} = 0.06$, $p > 0.05$) but the type of perception – action coupling used did interact significantly with the time of occlusion ($F_{4,124} = 7.73$, $p < 0.05$). Again this indicated that the relative prediction accuracy under the coupled and uncoupled response conditions varied according to the information sources available to the players. Follow-up testing revealed that the prediction accuracy for the coupled response was superior to the uncoupled response for the occlusion condition t5 in which ball-flight information was available ($t_{31} = 4.60$, $p < 0.05$), as it had been in experiment 1. No differences in prediction accuracy between the two response conditions were evident at occlusion period t3 or at any of the other pre-contact occlusion conditions (see figure 4). The superior prediction accuracy found for the uncoupled response condition at t3 in experiment 1 could not be replicated in this experiment, suggesting that the difference evident at this occlusion in the earlier experiment is likely to have been a spurious one.

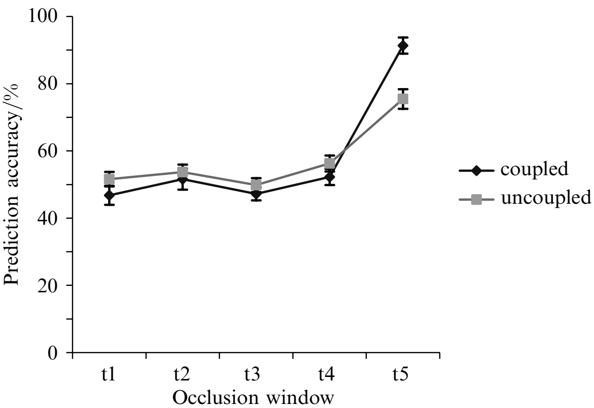

Figure 4. Prediction accuracy as a function of the occlusion window and response condition for experiment 2. Error bars represent standard errors.

The results from experiment 2 therefore reinforce some of the conclusions of experiment 1, and further clarify the nature of the relationship between the availability of kinematic and ball-flight information sources and coupled and uncoupled response conditions. In particular, the results consolidate the finding from experiment 1 that prediction accuracy is superior in the coupled response mode when ball-flight information is available. This lends further support to the notion of the existence of a dedicated processor for the prediction and interception of moving objects that can only be used fully and effectively in the natural context of coupled actions. The results of experiment 2 also reveal that the significantly higher prediction accuracy found at condition t3 for the uncoupled response in experiment 1 was not reproducible, and is therefore most likely to be simply a consequence of a random fluctuation in the performance levels of the players, particularly the novice ones, who participated in the first experiment. The lack of any differences between the response modes at any of the pre-contact occlusion conditions in this experiment, coupled with the absence of other pre-contact differences, with the exception of the t3 time window in experiment 1, supports the conclusion that there is no systematic difference in the prediction accuracy achievable under coupled and uncoupled response conditions when occlusion occurs before the contact.

4 General discussion

In the two experiments reported in this paper we examined the anticipatory performance of tennis players under two different response modes reflecting differing degrees of perception – action coupling. While the perceptual requirements were the same for both response conditions, the coupled condition required participants to attempt to return a tennis serve, whereas the uncoupled response, reflecting much of the previous laboratory-based expertise research, simply required a verbalised prediction of service direction. In both cases the display was systematically manipulated by using varying degrees of temporal occlusion.

In experiment 1 we found that the coupled response produced higher perceptual accuracy when ball-flight information was available; while the t3 occlusion condition, where only pre-contact information was available, produced superior perceptual accuracy within the uncoupled response (see figure 2). This finding points toward the possible use of differing perceptual systems by performers that depend upon the degree of coupling between perception and action and the content of the visual display. However, given some inconsistencies in whether or not response-mode differences were evident for occlusion presented prior to the ball being struck by the server and the absence of a complete theoretical explanation, further clarification was necessary. The results of experiment 2, where a group of intermediately skilled tennis players performed identical tasks to those performed by participants in experiment 1, provide support for prediction accuracy being superior for post-contact occlusions under coupled response-mode conditions but revealed no response-mode differences for occlusions occurring before the contact.

The collective findings of the two experiments provide support for the existence of a dedicated processor for visual prediction or interception that can be used effectively only in the natural context of coupled actions. It is plausible that the coupling of perception and action both for intercepting and for avoiding objects as they approach is an essential element to survival of the species, and that dedicated neural processors to handle such information may have evolved through millions of years of natural selection. The precision with which we can intercept moving objects, including catching and hitting balls (Alderson et al 1974; McLeod et al 1985), supports the contention that special automated processes for precise pickup of approach information may exist.

Importantly, in the current context, these processors (a) may only function optimally if action is required (explaining the superiority of the coupled response condition when approaching ball-flight information is available) and (b) are not suitable for information prior to ball flight (explaining the absence of the advantage of a coupled response for the conditions in which ball-flight information was not available). The latter would appear logical from an ecological standpoint given that there is no obvious evolutionary imperative for prediction of overarm throwing patterns of the type present in the tennis service action.

Data from experiment 1, in which skill level was also examined as an independent variable, also demonstrated that an expert advantage was present in prediction accuracy under the coupled response condition that was not apparent in the uncoupled response condition. This reinforces the importance of examining experts in their natural performance setting. Support for these contentions can be drawn from recent study of the relationship between expertise and the attentional processes used during coupled motor performance in a natural task setting. Beilock et al (2002) found that instructions directing a performer's attention to task-relevant cues enhanced the performance of novice soccer players performing a soccer dribbling task, yet were detrimental to expert players. They reasoned that such an instructional set forced the expert players to revert to some form of step-by-step processing of complex procedural knowledge; in the absence of intervention or instruction such processes may have occurred both more automatically and more efficiently. A similar argument can be advanced regarding the nature of the verbalised response condition in the current paper. Such a condition may have disrupted the expert's usual processing activities while assisting the performance of the novice players, thus causing the clear expert advantage evident in the coupled response condition to dissipate in the uncoupled response condition.

In summary, the findings of the current investigation indicate the potential existence of a specialised, dedicated processor for the perception of ball-flight information. However, the activation of this perceptual process depends upon the naturalness of the linkage between the perceptual information and the response mode required, being activated effectively only in conditions where the normal functional couplings of perception and action are preserved. Conversely, no evidence was found to support the existence of comparable evolved processes for the perception and prediction of more complex whole-body kinematics. This finding is consistent with, though by no means a direct test of, Milner and Goodale's (1995) conceptualisation of two different visual processing streams for perception and action processes. The results of this study also further verify the importance of examining motor experts in a testing environment that replicates their performance context as closely as possible. Without natural coupling of perception and action the full extent of expertise may be obscured and the potential to more fully understand processes impaired.

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