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THE RELATIONSHIP BETWEEN EXPERTISE AND VISUAL SEARCH STRATEGY IN A RACQUET SPORT *

Bruce ABERNETHY

University of Queensland, St. Lucia, Australia

David G. RUSSELL

University of Otago, Dunedin, New Zealand

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The visual search characteristics of 15 expert and 16 novice badminton players were recorded as they performed a film test designed to assess their anticipatory cue usage. Experts were found, from the film task, to be able to pick up earlier advance information than novices and this appeared to be related to their reliance upon the arm, in addition to the racquet, as a source of anticipatory information. These differences in information-extraction, however, were not matched by differences in visual search characteristics with the location, duration and sequence of the novices' fixations on the film display being indistinguishable from those of the experts. It is concluded therefore that the major source of expertise-related differences in sport perception is not the visual search (or reception) strategy per se but rather the use to which the received information is subsequently put. Some experimental and practical implications of the observed discrepancy between visual orientation and information-extraction are considered and the normal search strategy adopted in badminton by both expert and novice players is described in some detail.

In a recent paper we (Abernethy and Russell 1987) demonstrated fundamental differences in selective information pick-up between ex-

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Requests for reprints should be sent to B. Abernethy, Dept. of Human Movement Studies, University of Queensland, St. Lucia, 4067, Australia.

pert and novice racquet sport players. Experts, when faced with a film simulation of the perceptual display in badminton, were shown to have superior anticipatory skills to novices and this appeared to be a consequence of their capability to pick up information from some advance cue sources which the novices could not utilize. Advance prediction of stroke direction and speed appeared to be made by experts from cues arising from both the racquet and the arm holding the racquet whereas novices seemed only capable of extracting advance information from the racquet itself. In this paper we attempt to determine whether these differences in anticipatory cue usage are a consequence of fundamental differences in the visual search strategies utilized by the two groups.

Previous studies of visual search activity in 'real-world' activities like sport (e.g., Bard and Fleury 1976, 1981; Bard et al. 1980; Neumaier 1982, 1983; Vickers 1984) and ergonomics (e.g., Kundel and La Follette 1972; Megaw and Richardson 1979; Mourant and Rockwell 1972; Stern and Bynum 1970) have revealed some systematic differences between expert and novice performers in terms of their distribution of ocular fixations to available features of the display and these differences have generally been taken as indicative of differences in selective attention. Similarly, in keeping with notions derived from simple laboratory studies of search rate being proportional to situational uncertainty (Teichner and Krebs 1974; Teichner and Mocharnuk 1979), some evidence for experts searching the display at a slower rate than novices, and hence using fewer fixations of longer mean duration, has been forthcoming (e.g., Bard and Fleury 1976; Bard et al. 1980; Haase and Mayer 1978; Papin et al. 1984) but this evidence is far from unequivocal (cf. Schoonard et al. 1973; Stern and Bynum 1970). Unfortunately much of the existing applied research uses static display presentations, is based on small sample sizes and is fraught with inherent design limitations and assumptions. Almost without exception the assumption is made that the orientation of foveal vision and the allocation of visual attention are related in a simple 1 : 1 fashion and no consideration is given to the possibilities of subjects moving their attention throughout the visual field without making eye movements (Posner 1980; Posner et al. 1980; Remington 1980; Shulman et al. 1979) or of the important distinction between 'looking', as implied from visual orientation to a display region, and 'seeing', as implied from actual information-extraction (Adams 1966). (For fuller reviews of the existing applied visual search literature and the assumptions and limitations in the use of eye movement recording see Abernethy (1985, 1987).)

It was the purpose of the experiment reported in this paper therefore to examine the relationship between selective information pick-up and visual search activity as it relates to skilled performance in a racquet sport. Subjects' eye movements were recorded as they performed a concurrent film task designed to assess the time and spatial location of the critical anticipatory cues used by players in the racquet sport of badminton. It was hypothesized, in keeping with previous visual search studies and our own behavioural data on information pick-up, that experts would be characterized by a search strategy which has a higher proportion of foveation on the opponents' racquet and arm and which operates at a slower rate, than that used by novices. In performing this study it was also hoped to glean some hitherto unavailable information on the visual search process as it operates within racquet sports.

Method

Subjects

The subjects were 15 expert badminton players, who were participants in the VIIth Commonwealth Games in Brisbane, Australia, and 16 novice badminton players who were undergraduate students in physical education. The expert group ranged in age from 18 to 32 years and consisted of 12 males and three females whilst the novice group ranged in age from 18 to 29 years and consisted of 11 males and five females. Participation by all subjects was on a voluntary basis. [1]

Film task design

The film task used to assess the temporal and spatial characteristics of the subjects' anticipatory cue usage was the same as reported in our earlier study (Abernethy and Russell 1987). This film was constructed in the following manner. A 16 mm camera was positioned in the centre

[1] The groups used in this experiment were actually a sub-set of the groups reported in Abernethy and Russell (1987).

of the receiver's court in badminton and set to a height of 1.70 m above court level. This filming position was chosen in an attempt to best simulate the normal viewing position of the receiving player in badminton. From this position a provincial level male badminton player was filmed whilst executing a series of badminton strokes into the receiver's court. This original film was then selectively edited so as to manipulate either the time course of information available to the viewer (temporal occlusion) or the degree of visibility to selected display features (event occlusion). In the first half of the film 32 different badminton strokes were presented to the subjects under five, randomly ordered, conditions of temporal occlusion. These temporal occlusion conditions were:

t1: Occlusion of the display occurred 4 frames (≑ 167 msec) prior to racquet–shuttle contact;
t2: Occlusion of the display occurred 2 frames (≑ 83 msec) prior to racquet–shuttle contact;
t3: Occlusion of the display occurred at the point of racquet–shuttle contact;
t4: Occlusion of the display occurred 2 frames (≑ 83 msec) subsequent to racquet–shuttle contact;
t5: No occlusion of the display occurred until all outward flight of the shuttle was completed.

In the second half of the film these same 32 strokes were presented under five conditions of event occlusion, with, in each case, the display being also temporally occluded at the point of racquet–shuttle contact. These event occlusion conditions, which were created by placing letraset masks on the film positive, were:

e1: The player's racquet and arm holding the racquet were occluded;
e2: The player's racquet (but not the arm holding it) was occluded;
e3: The player's face and head were occluded;
e4: The player's lower body was occluded;
e5: Irrelevant background features were occluded.

An intertrial interval of 5 sec was provided throughout the film.

Apparatus

A Polymetric Mobile V0165 Eye Movement Recorder, with an accuracy of 1° within horizontal and vertical ranges of +/− 10°

(Young and Sheena 1975) was used to record the subjects' visual search patterns. Eye movements were recorded onto video-tape using an RCA Ultricon TC2014 UX low-light video camera coupled to a JVC HR-7600MS player-recorder and were simultaneously displayed onto a Sony PVM-1370QM high resolution monitor placed out of the subject's field of view.

Procedures

The eye movement recording apparatus was first fitted onto the subjects' head and stabilized through the use of a waxen bite-bar. The eye movement recorder was then calibrated for both position and linearity to ensure that the fixation mark (a light spot reflected from the subject's left cornea) corresponded precisely to the subject's visual orientation to different sectors of the viewing screen and this calibration was checked repeatedly throughout the course of the experiment. The film task was then presented to the subjects by projecting the constructed film onto a white screen set 4 m in front of the subjects at eye level. A projector-to-screen distance of 5 m was used and this enabled a 1.00×0.75 in. image size to be generated. Subjects were instructed to predict, from the information available to them on each trial, the probable landing position of the opponent's stroke. Subjects were required to make this landing position prediction as soon as possible after the film trial's completion and to respond by placing a cross on a response sheet which was a scaled representation of a badminton court. Subjects were further instructed to return their visual focus to the screen centre immediately upon completing their response and on any occasion where this visual orientation was not apparent from the monitored eye movements the film was stopped and re-calibration of the eye mark was performed. [2]

The film task presented to the subjects in this experiment therefore represented an attempt to simulate, within the bounds of acceptable experimental control and replicability, the perceptual demands of the 'real-world' activity of playing badminton. An attempt was made to preserve the stimuli within their normal context although clearly the task facing the subjects varies from the 'real-world' act with respect to

[2] An earlier pilot study had indicated that the subject's prediction performance on the film task was not impaired by the wearing of the eye movement recording apparatus.

its response requirements. Without the utility of remote field recording of the subject's eye movements it is difficult to ascertain the extent to which this de-coupling of the normal perception–action link in this experimental task may have influenced the subject's search patterns. As a consequence observations made in the following sections with respect to expert–novice differences in visual search strategy are necessarily directed to performance on this film per se with any inferences made to expert–novice differences in actual playing performance being necessarily tentative ones.

Analysis of data

Film task data

The subject's prediction accuracy under each of the temporal and event occlusion conditions was determined using the procedures outlined in our previous study. The discrepancy between the actual landing position of the shuttle and the subject's prediction of the landing position (termed radial error) was calculated for each trial and then analysis of variance procedures were used to determine the effect of the factors of skill level and occlusion condition upon this prediction error. Two-way (group × occlusion condition) analyses of variance were conducted independently for both the temporal occlusion trials and the event occlusion trials and, in addition, a separate analysis of variance was computed for the event occlusion trials using radial error differences between the control condition (e5) and each of the other occlusion conditions as the dependent measure.

Visual search data

The visual search patterns used by each of the subjects in the performance of the film tasks were analyzed frame-by-frame using a video player-recorder (viz. a JVC HR-7600 MS player-recorder as described in the data capture configuration) which allowed reliable location of sequential video frames. Ocular fixations for each of the 320 trials per subject were described in terms of both their location and duration characteristics. In order to derive locational data the display was divided into discrete zones and fixations into each of these zones were recorded using the following arbitrary codes:

r = fixations on the opponent's racquet and arm region;
s = fixations on the shuttle during its outflight;

t = fixations on the opponent's trunk and body centre;
h = fixations on the opponent's head and face;
f = fixations on the opponent's legs and feet. [3]

Fixations on the screen during the inter-trial interval and prior to film trial commencement were also coded (using the symbol 'x'), as were on-screen fixations after film occlusion (symbol 'y'). Fixations which were either to an unnamed region of the display or whose location could not be clearly identified (e.g., due to calibration difficulties) were designated using the symbol 'n'. A fixation in all cases was operationally defined as any state in which the eye mark remained stationary for a period equal to, or in excess of, 3 frames (120 msec).

Given a video sampling rate of 25 frames/sec these coded input data were then used to compute the following series of dependent measures:

- *Visual correction time*, which was the time between when the film display first appeared and when the first saccadic eye movement to the new display was made;
- *Dwell time*, which was the time the eye remained fixated upon the screen after the film trial had been completed and the display occluded;
- *Mean fixation duration* ($\overline{FD}$), which was the average duration of all fixations occurring during, or transcending the film trial's appearance;
- *Percentage of film trial time per cue* (%r, %s, %t, %h, %f, %x and %n), which were the percentages of the actual film trial time which were spent at each one of the locations outlined previously.

On trials in which the visual search data could not be extracted from the video record mean parameter values were supplied by taking the average value of the search characteristics used in performing the other film trials of the same stroke and occlusion type.

These dependent measures were then used to compare the search strategies of the expert and novice performers in terms of fixational location, order and duration characteristics. The distribution of fixation

[3] The precision with which the eye movement recorder could determine the fixation locations prevented any finer division of the display and prevented, for example, the desirable discrimination between fixations on the forearm and fixations on the racquet head.

locations for each skill group were compared by performing a series of two-way analyses of variance on each of the percentage film trial time per cue measures, using as factors the subject's skill level and the specific film occlusion conditions. Similar two-way analyses of variance were conducted on the $\overline{FD}$ parameter, to determine possible differences in search rate, and upon the visual correction time and dwell time measures and in all cases the source of any significant main or interactive effects were sought using the Newman-Keuls post-hoc procedure. Frequency distributions were also plotted in the case of the *FD* measure to gain a further indication of search rate characteristics. Finally search order characteristics were analyzed by determining the percentage of occasions in which fixations at each location preceded, or were themselves preceded by, fixations from each and every other area of the display. This determination of sequential dependencies was only conducted on trials in which full display information was presented (i.e., t5) and hence only upon trials in which all cues had an opportunity of being fixated.

Results and Discussion

Film task performance

Temporal occlusion conditions

Fig. 1 displays the error in prediction of the shuttle's landing position as a function of the extent of temporal occlusion for the expert and novice groups. A significant interaction exists between the skill level of the subjects and the extent of temporal occlusion of the display ($F(4,116) = 7.736$, $p < 0.05$) with significantly lower prediction error evident for the expert players under all occlusion conditions except t1. As was the case when this analysis was performed previously (Abernethy and Russell 1987) on a larger ($n = 55$) sample of subjects, the distinguishing characteristic which emerges for the expert group is their ability to extract early advance information between t1 and t2. Novices in the same time period, from 167 msec to 83 msec prior to the point of racquet–shuttle contact, cannot apparently extract information which is of use in resolving uncertainty about the forthcoming stroke's direction and force.

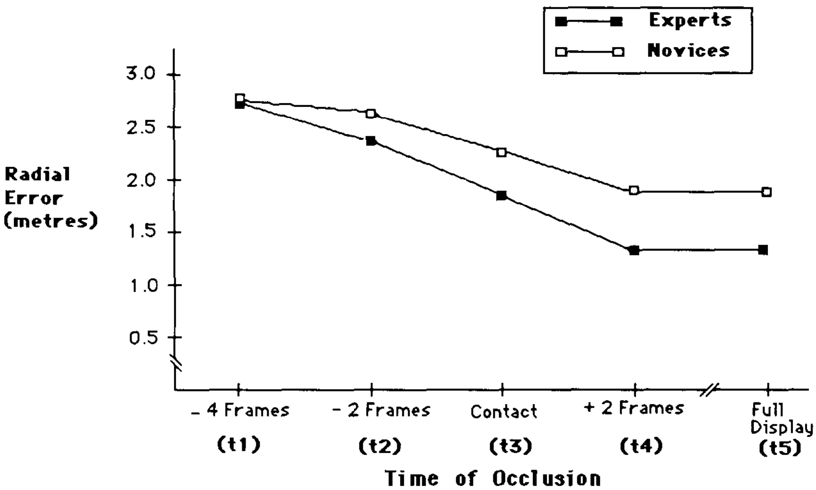

Fig. 1. Error in predicting the landing position of the shuttle as a function of the degree of temporal occlusion for the expert ($n = 15$) and novice ($n = 16$) performers.

Event occlusion conditions

These differences in anticipatory capability between the expert and novice performers are again mirrored by differences in cue usage. When the prediction performance of the expert and novice groups is compared under the different conditions of event occlusion (fig. 2) significantly greater radial error is evident for the novice group under all conditions except el ($F(4,116) = 7.275$, $p < 0.05$), that being the condition where visibility to both the arm and racquet is occluded. For the expert group both the racquet and the arm emerge as significant sources of anticipatory information (condition el having greater error than e2 with both these conditions inducing more error than the control condition e5). For the novice group only the racquet emerges as a significant anticipatory cue with the radial error induced by arm and racquet occlusion (el) being the same as that under racquet occlusion conditions (e2) alone. These fundamental differences in the selective information pick-up of experts and novices, which are consistent with our previous study, become more apparent when the differences in anticipatory performance between the two skill groups under control conditions (e5) are partialled out through the computation of difference scores (see fig. 3).

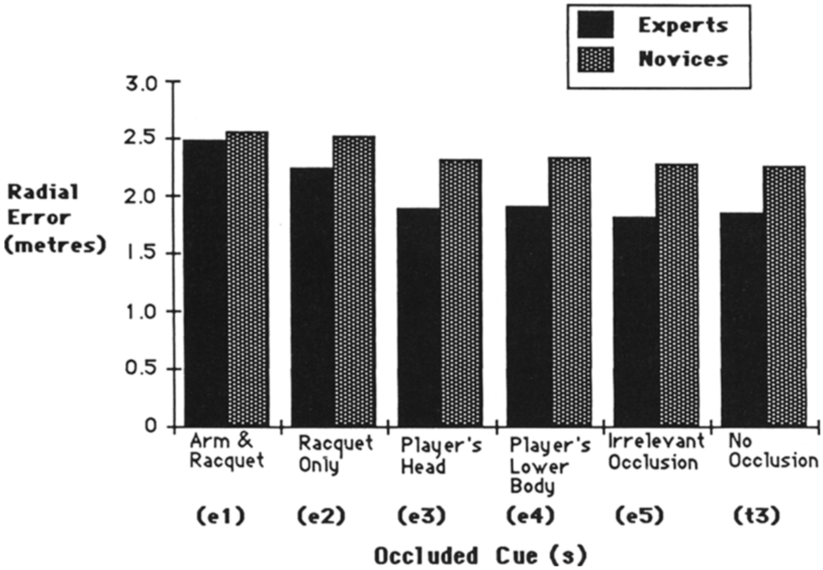

Fig. 2. Error in predicting the landing position of the shuttle as a function of event occlusion for the expert and novice performers.

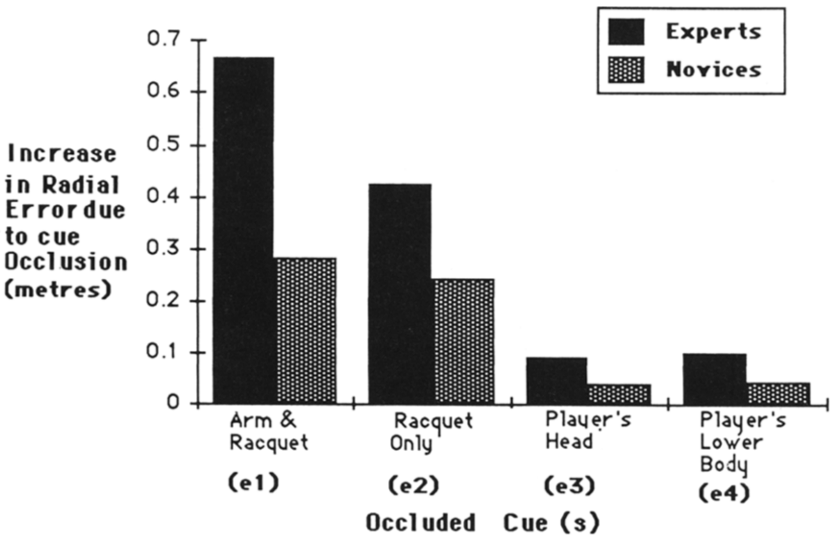

Fig. 3. Increases in prediction error attributable to specific cue occlusion for the expert and novice groups (increases are expressed relative to the control condition e5).

Given that there are these consistent differences in information-extraction from different display cues between the expert and novice performers in this example, just as there were in the larger sample reported previously, the important issue is therefore whether these differences in information pick-up can be attributed to differences in visual search strategy. The characteristics of the visual search strategies used by the expert and novice performers are considered in the sections that follow.

Search sequence characteristics

The normal search sequence utilised by the expert and novice subjects was determined through the computation of a series of transition matrices. Each one of the transition matrices provided an indication of the percentage of occasions in which a given fixation location was immediately preceded, or followed, by fixations from each of the other display areas. The first of these matrices examines the distribution of the fixation locations at the start of the search sequence.

Fixation locations following screen centre fixations

As each film trial inevitably commenced with the subjects fixating upon the screen centre, an indication regarding the early orientation of the performers' visual search can be gained by analyzing the relative frequency of fixation locations immediately following screen centre fixations. When such an analysis is performed it becomes apparent that the racquet and the opponent's head, trunk and, to a lesser extent, lower body are the most frequently used locations early in the search sequence (table 1). Although the same major areas of the display attract early fixations from both experts and novices there was a trend towards experts making a higher proportion of early fixations upon the racquet region and a lower proportion of fixations to the opponent's head, trunk and feet.

What then occurs in the search sequence if fixation proceeds to one of these other areas of the display?

Fixation locations preceding and following lower body fixations

The most frequent fixation locations prior to, and subsequent to, fixations upon the opponent's lower body are presented in table 2. Fixations on the lower body follow either screen, racquet, trunk or

Table 1
Relative frequency of fixation locations immediately following screen centre fixations.

Skill groups	Following fixation location (%)						
	Screen centre (x)	Lower body (f)	Trunk (t)	Head (h)	Racquet & arm (r)	Shuttle (s)	Not determinable (n)
Experts	5.66	2.83	16.71	15.42	46.27	0.00	13.11
Novices	4.04	4.75	28.74	28.98	24.47	0.00	9.03

other lower body fixations with approximately equal frequency. After a fixation has been made on the lower body, however, the most predominant subsequent location is clearly the racquet, indicating that, in the normal search sequence, lower body fixations usually occur prior to those on the racquet. Once a shift in orientation is made to the racquet, fixation is returned relatively infrequently. The role of the lower body in the search sequence was found to be relatively consistent one with no obvious differences between the skill groups with respect to search of this area of the display.

Fixation locations preceding and following trunk fixations

Fixations upon the opponent's trunk occur primarily early in the visual search sequence, with some 80% of all trunk fixations occurring

Table 2
Relative frequency of fixation locations (a) preceding and (b) following fixations upon the opponent's lower body.

Skill groups	Fixation locations (%)						
	Screen centre (x)	Lower body (f)	Trunk (t)	Head (h)	Racquet & arm (r)	Shuttle (s)	Not determinable (n)
	Preceding fixation location (%)						
Experts	28.57	16.67	21.43	2.38	21.43	4.76	4.76
Novices	21.36	22.33	26.21	10.68	15.53	0.00	3.88
	Following fixation location (%)						
Experts	–	16.67	7.14	0.00	61.90	0.00	9.52
Novices	–	22.33	10.68	1.94	58.25	0.00	2.91

Note: In the remaining 4.76% of cases for the experts and 3.88% of cases for the novices lower body fixations were the final fixations in the search sequence.

Table 3
Relative frequency of fixation locations (a) preceding and (b) following fixations upon the opponent's trunk.

Skill groups	Fixation locations (%)						
	Screen centre (x)	Lower body (f)	Trunk (t)	Head (h)	Racquet & arm (r)	Shuttle (s)	Not determinable (n)
	Preceding fixation locations (%)						
Experts	84.62	2.88	4.81	3.85	3.85	0.00	0.00
Novices	76.55	5.26	9.57	2.87	3.83	0.00	1.91
	Following fixation locations (%)						
Experts	–	8.65	4.81	9.62	71.15	0.00	5.76
Novices	–	12.92	9.57	4.31	66.99	0.48	4.78

Note: In the remaining 0.96% of cases for the novices trunk fixations were the final fixations in the search sequence.

immediately after fixations on the screen centre. As was the case with lower body fixations, visual orientation is usually shifted from the trunk immediately to the racquet (see table 3) although on a number of occasions fixations to either of the body extremes (i.e., either the head or the lower body) also occur. Minimal differences in the sequential characteristics of the expert and novice group's visual search were apparent with respect to the use of trunk cues, again indicating the persistence of some common visual search characteristics across the different skill groups.

Fixation locations preceding and following head fixations

Fixations on the opponent's head, like trunk fixations, occur with greatest prevalence early in the visual search of the display – on average some 76% of all fixations on the head and face region occupying first position in the search sequence. As with the other fixation locations examined thus far, the racquet region is the most frequently searched location following fixations upon the opponent's head (see table 4), although in some 12% of cases an additional fixation on the head is also made. Once the eye has moved from fixating upon the opponent's head to fixating upon the racquet and surrounding areas there is only a very low probability of foveal vision being returned. No marked skill group differences were evident in the role of fixations

Table 4
Relative frequency of fixation locations (a) preceding and (b) following fixations upon the opponent's head.

Skill groups	Fixation locations						
	Screen centre (x)	Lower body (f)	Trunk (t)	Head (h)	Racquet & arm (r)	Shuttle (s)	Not determinable (n)
	Preceding fixation locations (%)						
Experts	77.39	0.00	8.70	7.83	4.35	0.00	1.74
Novices	75.11	0.90	4.07	16.74	1.36	0.00	1.81
	Following fixation locations (%)						
Experts	–	0.87	3.48	7.83	79.13	0.00	8.70
Novices	–	4.98	2.71	16.74	72.85	0.00	2.71

upon the opponent's head in the composite search sequence, with the possible exception of the observation that experts are less likely than the novices to make a second (or series) of fixations upon the head.

Fixation locations preceding and following racquet fixations

As the racquet appears to be a terminal fixation location for many of the other cues already examined, analysis of racquet sequential information appears potentially very important in the derivation of a clearer description of the general search pattern. Analysis of the relative frequencies of fixation locations preceding and following racquet fixations (table 5) reveals that, although a wide range of fixation locations are seen to precede fixations on the racquet (viz. the screen centre, the opponent's head, trunk and lower body), once visual focus is shifted to the racquet it either remains there or moves on to observation of the shuttle in it's outward flight. This implicates the racquet as the region of highest priority and implicates an essentially dominant role for this cue source especially late in the search sequence. Minimal differences in the use of the racquet as a visual cue were evident between the skill groups, either in terms of the preceding or the following fixation locations, again suggesting a relative generality in the sequential nature of the visual search adopted by all subjects.

Fixation locations preceding and following shuttle fixations

Fixations upon the shuttle in its outward flight are preceded, almost universally, by racquet fixations (table 6). Once the shuttle has been

Table 5
Relative frequency of fixation locations (a) preceding and (b) following fixations upon the opponent's racquet and arm.

Skill groups	Fixation locations						
	Screen centre (x)	Lower body (f)	Trunk (t)	Head (h)	Racquet & arm (r)	Shuttle (s)	Not determinable (n)
	Preceding fixation locations (%)						
Experts	19.74	2.58	7.34	9.03	54.66	0.10	6.55
Novices	9.78	5.19	12.11	13.93	54.58	0.00	4.41
	Following fixation locations (%)						
Experts	–	0.89	0.40	0.50	54.66	7.04	2.19
Novices	–	1.38	0.69	0.26	54.58	9.95	1.21

Note: In the remaining 34.32% of cases for experts and 31.92% of cases for novices racquet and arm fixations were the final fixations in the search sequence.

fixated, the most probable subsequent fixation is a further sample of shuttle outflight, although, in the majority of instances, the shuttle is the last cue fixated prior to film trial cessation. Again this effect regarding the position of shuttle fixation within the search sequence was found to hold across both skill groups.

Table 6
Relative frequency of fixation locations (a) preceding and (b) following fixations upon shuttle outflight.

Skill groups	Following fixation location (%)						
	Screen centre (x)	Lower body (f)	Trunk (t)	Head (h)	Racquet & arm (r)	Shuttle (s)	Not determinable (n)
	Preceding fixation location (%)						
Experts	0.00	0.00	0.00	0.00	92.21	6.49	1.30
Novices	0.00	0.00	0.74	0.00	84.56	14.71	0.00
	Following fixation location (%)						
Experts	–	2.60	0.00	0.00	1.30	6.49	0.00
Novices	–	0.00	0.00	0.00	0.00	14.71	0.00

Note: In the remaining 89.61% of cases for experts and 85.29% of cases for novices shuttle fixations were the final fixations in the search sequence.

Table 7
Relative frequency of fixation locations occupying the final position in the search sequence.

Skill groups	Final fixation location (%)					
	Lower body (f)	Trunk (t)	Head (h)	Racquet & arm (r)	Shuttle (s)	Not determinable (n)
Experts	0.47	0.00	0.00	70.33	15.65	2.10
Novices	0.00	0.20	0.00	51.49	21.78	2.18

Note: In 11.45% of cases for experts and 24.36% of cases for novices fixations on the screen centre after film occlusion were the last fixations in the search sequence.

Final fixation location occurrences

Table 7 presents the average percentage of trials in which each particular fixation location occupies the final position in the search sequence. The racquet has the highest probability of being the final fixation in the search sequence, followed by the shuttle, indicating that although shuttle flight information is always available it is sampled foveally on a relatively limited number of occasions. In some 18% of cases in which full display information was available to the subjects further fixations occurred on the screen after the film trial's cessation and this possibly reflects the subject's uncertainty about the information presented or perhaps reflects an attempt by the subjects to utilize any available iconic persistence of the visual stimulus to further enhance response selection. Some possible expertise-related differences in final fixation location were also evident. Experts appeared to have the racquet as the final fixation in their search sequence more often than the novices who, in contrast, appeared to place greater reliance on the shuttle and additional on-screen fixations after the film occlusion. These differences perhaps reflect the redundant nature of much of the shuttle outflight for experts (cf. fig. 1) and the consequent lack of necessity, for experts to fixate upon the shuttle in flight in order to generate predictions about its ultimate landing position.

Conclusions regarding the search sequence

The sequential analyses, along with subjective observations of the search patterns, suggest that the following search sequence was common to most subjects, irrespective of their level of expertise.

Subjects initially prepared themselves for the film trial onset by fixating in proximity to the screen centre, thereby adopting a strategy which not only satisfied the instructional set provided but which also provided the highest potential for early location of the target object (i.e., their opponent). Once the film display appeared there was some inevitable latency before the subjects made their first saccadic eye movement and this saccade was generally directed to gross regions of the opponent's body such as the trunk, head or lower body. It would appear that these initial fixations were primarily concerned with providing the subjects with early visual information regarding the opponent's direction of movement and regarding whether the developing posture was that for a forehand or backhand stroke. As soon as the opponent's stroke execution commenced the obvious priority become that of spending as much time as possible with the racquet as the point of regard. This area of the display clearly provided the cues to which all subjects assigned greatest pertinence. The racquet was, in most cases, the source of a number of successive fixations (see table 5) with the point of fixation periodically altered to maintain a match with the motion of the racquet (and arm). In a substantial number of cases these racquet fixations occurred without prior fixations on the opponents' body.

Once the racquet had made contact with the shuttle visual focus was frequently shifted to the monitoring of shuttle flight although in many cases fixation remained upon the racquet even after these more specific cues for landing position become available. In those cases where fixations were made upon shuttle flight, shuttle flight was very rarely sampled exhaustively and movement of the head away from the display frequently preceded the cessation of full display information. This observation of broken monitoring of shuttle outflight suggests that the majority of information conveyed by the shuttle late in its flight is redundant, acting only to provide information to confirm perceptual judgments made much earlier in the stroke sequence. This concept of late shuttle flight redundancy is congruent with the earlier observed asymptotes in prediction performance in the temporal occlusion trials (viz. t4–t5; see fig. 1) and with the observation that the ocular tracking of real ball flight is generally incomplete, being broken some distance before racquet or bat contact (e.g., Bahill and LaRitz 1984; Hubbard and Seng 1954; Stein and Slatt 1981). In the instances where shuttle flight was maintained in the early stages of flight it was done through the use of saccadic rather than smooth pursuit (or tracking) eye movements or, in Gregory's (1966) terms, through the use of the image–retina system rather than the eye–head system. This observation obviously brings under substantial question studies which attempt to differentiate expert and novice performers on the basis of simple ocular tracking tasks (e.g., Trachtman 1973) and approaches which attempt to enhance skill acquisition through training the eye–head system alone (e.g., Revien and Gabor 1981).

The bulk of the visual search sequence reflects a close match to the changes in the kinetic and kinematic properties of the opponent's stroke. In keeping with the force generation and transfer changes from proximal to distal segments of the body in the production of the forehand and backhand motions (Plagenhoef 1971) there appears to be a corresponding evolution of the visual search sequence from an initial proximal orientation (with fixations on the lower body, head and especially the trunk of the opponent) to a later dominant distal orientation (with fixations upon the racquet and supporting limb extremities). This close matching of visual search parameter changes with environmental changes is supportive of the matching effects reported previously with static problem-solving tasks (Just and Carpenter 1976) and implicates a close logical link between the search patterns and the potential information content of the display. Some of the existing German studies of visual search in sport (e.g., Neumaier's 1982 data from gymnastics observers or Möckel and Heemsoth's 1984 data from trained observers of the shot put event) also appear to show this close approximation of visual search to the emerging biomechanical characteristics of the action being viewed.

Although some individual differences in search sequences are evident [4] systematic proximal-to-distal search strategies occur across both the expert and novice skill groups. It therefore appears that the time constraints imposed by the use of a dynamic display task may act to restrict somewhat the search orders which are possible. Tasks in which a dynamic display is used, such as in this experiment and in the rifle shooting study by Ripoll et al. (1985), appear to encourage subjects to use far more predictable orders of search than are apparent when either the display is static or the search task is not time-constrained (cf. Buchsbaum et al. 1972; Gale and Findlay 1983; Yarbus 1967). Such a finding is hardly surprising when one considers that in a static display

[4] Three of the novices and two of the experts used a strategy, up until the point of racquet–shuttle contact, in which visual focus was occasionally alternated between the feet and the racquet.

situation all sections of the display may be potentially equally informative whereas in a dynamic situation informativeness is restricted primarily to those spatial regions which contain features changing as a function of time.

In short then, the selection of the next fixation location in this task appears to be primarily a function of the relative time of cue occurrences within the event sequence (e.g., a trunk fixation is more likely to occur early, rather than late, in the search) and the apparent necessity to locate and fixate upon the high priority racquet cues for as long a period as possible. The extent of this priority to the racquet region can be best gauged from the analyses of the fixation location distributions.

Search location characteristics

Fig. 4 presents the mean percentage of trial time which is spent with the eye fixated on each of the major sections of the display. As suggested from the earlier sequential analyses, both expert and novice subjects allocate visual priority to the racquet region with fixations upon other regions of the display being of clearly sub-ordinate importance. Significant differences were observed between the skill groups in terms of greater allocation of available trial time by the novices to fixations upon the head ($F(1,29) = 5.656$, $p < 0.05$), trunk ($F(1,29) = 6.703$, $p < 0.05$), and shuttle ($F(1,29) = 8.628$, $p < 0.05$), but these differences, because of the small absolute time allocated to these cue sources by both experts and novices, are of little practical consequence. Within the limits of the spatial isolation of display regions set by the eye movement recording apparatus, the allocation of foveal vision appears to be essentially similar regardless of the level of expertise of the viewer – a finding at variance with many of the earlier studies of visual search in sport (e.g., Bard and Fleury 1976; Bard et al. 1980). There are nevertheless some obvious commonalities with other studies of sports where the predominant action involves the use of the hands (e.g., as in volleyball reception (Neumaier 1983)) or some extension of the hands (e.g., as in fencing (Bard et al. 1981) or ice-hockey goal-tending (Bard and Fleury 1981)) in that the principal areas of fixation are the hand and arm or the implement held in the hand, with the head, face (the major 'non-verbal linear' (Ekman and Friesen 1969)) and the lower body very rarely fixated.

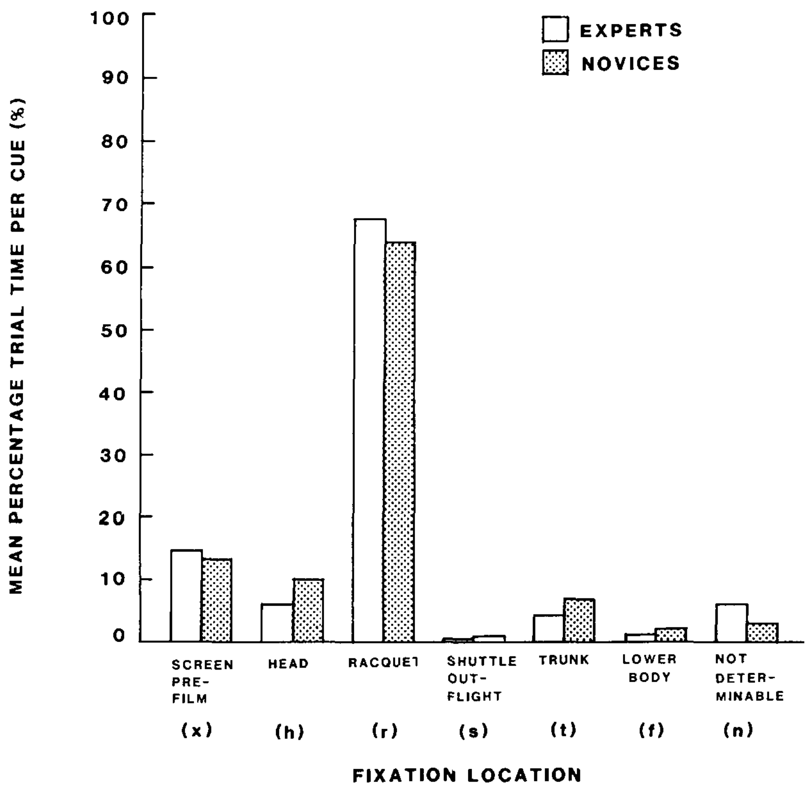

Fig. 4. Percentage of trial time allocated to each fixation location for the expert and novice performers.

Methodologically, the most important single concern within the visual search analysis is to determine the extent to which cue priorities implied from the fixation location distributions match the cue priorities for information extraction, as determined from the earlier event occlusion analysis. Fig. 5 presents, from the event occlusion analyses, the respective contributions to prediction performance which are attributable to information available from the player's racquet and arm (e1), head (e3) and lower body (e4) and compares this to the percentage time which is normally spent in fixating upon these different areas in each trial. Both analyses lead to the same general conclusions regarding the respective importance of cues from these three global regions of the display in prediction of the forthcoming landing position of the shuttle.

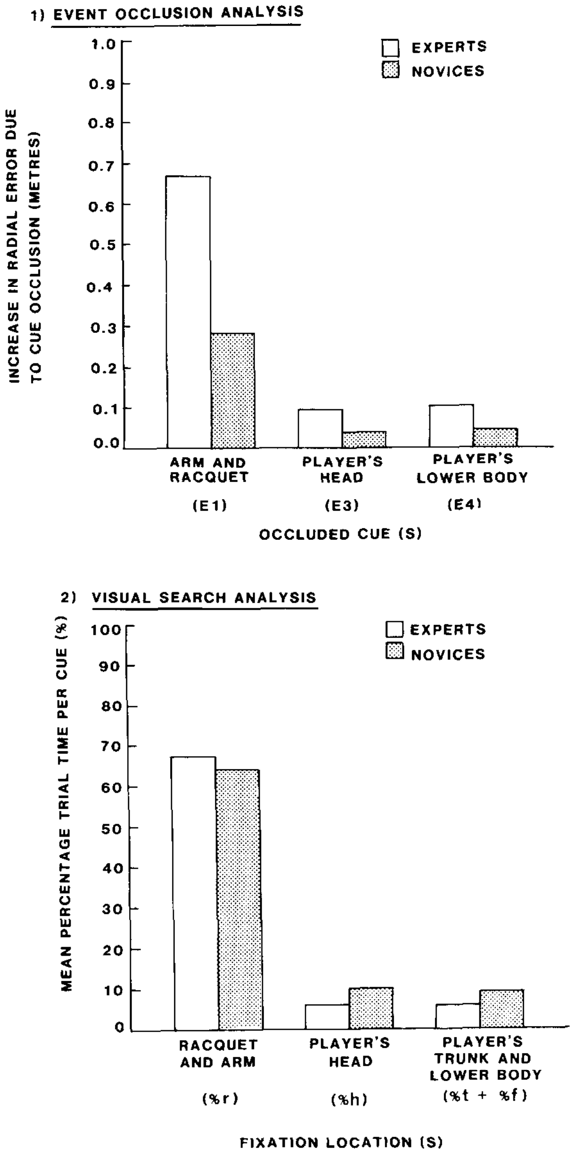

Fig. 5. Respective importance of different display cues for the expert and novice groups as determined from (1) the event occlusion analysis and (2) the visual search analysis.

Specifically both methods lead to the conclusion that the racquet (and possibly also the arm) is the most critical source of advance information and that the opponent's head, trunk and lower body are relatively unimportant – conclusions which are also compatible with the performers' own estimates of their cue usage.

There are, however, some discrepancies between the two skill groups with respect to their capabilities to extract information from given fixation locations. The event occlusion analyses show differences in the capability of the expert and novice players to extract information from the racquet and arm region (due to the expert's greater utilization of advance information from the arm action; see figs. 2 and 3), yet these differences are not mirrored by differences in the fixation distributions. It appears that although both experts and novices fixate for equal periods of time upon the region of the racquet and the supporting arm, only the experts have the necessary prior knowledge of the distinctive and relational features of the display (Gibson 1969) to extract usable information from the arm. There is clear evidence here therefore of differences between information extraction, as implied directly from the event occlusion method, and visual orientation, as gleaned from the visual search analysis, and a clear example of the limitations in eye movement recording alone in providing definitive information about selective information pick-up. Such limitations in eye movement recording have been infrequently recognized in the majority of applied visual search studies (Abernethy 1987), where selective attention has been repeatedly implied from fixation distribution data alone, in the absence of any concurrent measures of actual information extraction.

The allocation of the available viewing time to fixations on different display areas varies quite systematically as a function of the duration of display information which is available (table 8). With increased availability of temporal information (in the transition from condition t1 through to t5) there is a progressive increase for both experts and novices in the percentage of each trial which is allocated to fixations on the racquet and shuttle and a progressive decrease in the allocation of viewing time to other cue sources. In keeping with the conclusions reached earlier regarding the search sequence this analysis also clearly supports the proximal-to-distal notion of search progression with a greater reliance on trunk, head, lower body and screen centre fixations early rather than late in the stroke sequence and an almost singular reliance on cues from the racquet and shuttle late in the stroke's development.

In contrast, the distribution of fixations is essentially uninfluenced by event occlusion manipulations of the film display (see table 9).

Table 8
Mean percentages of trial time allocated to each fixation location expressed as a function of both temporal occlusion and expertise.

Fixation location		Temporal occlusion conditions				
		t1	t2	t3	t4	t5
Racquet (%r)	Experts	67.48	65.75	68.74	68.28	69.92
	Novices	60.87	61.01	64.85	66.93	60.58
Shuttle outflight (%s)	Experts	0.00	0.00	0.06 [a]	0.18	6.25
	Novices	0.00	0.00	0.00	0.02	10.23
Trunk (%t)	Experts	5.36	5.41	4.87	5.36	3.27
	Novices	8.20	8.58	7.68	6.76	6.90
Head (%h)	Experts	6.64	7.88	6.45	6.98	5.21
	Novices	11.91	11.73	10.95	9.35	9.00
Feet (%f)	Experts	1.29	1.67	2.39	1.94	1.62
	Novices	3.94	4.04	3.00	3.40	2.68
Screen centre (%x)	Experts	12.61	12.06	11.60	10.39	8.71
	Novices	11.39	10.46	9.50	8.90	7.50
Not determinable (%n)	Experts	6.78	7.55	5.89	6.86	5.03
	Novices	4.08	4.34	4.02	4.63	3.15

[a] Anticipatory saccades for shuttle outflight.

Although some very minor reductions in the searching of specific cues are evident when visibility to these cues is occluded the most striking feature is how little effect specific cue occlusion has upon the search sequence. In the case where the racquet and arm are occluded (e1), for example, the eye still fixates upon those regions (or where the cues should be) for some 64% of the available viewing time even though no information is available from these areas. This observation therefore supports in principle the capability of the event occlusion paradigm to make controlled comparisons of cue usage without causing the subject to elicit atypical or adaptive search patterns.

Subjects from both skill groups show remarkably little adaptability to cope with the altered task demands brought about by each specific event occlusion condition. Changes in search pattern characteristics during the course of a trial are apparently difficult to make because the trial durations are short enough that insufficient time exists to substan-

Table 9
Mean percentages of trial time allocated to each fixation location expressed as a function of both event occlusion and expertise.

Fixation location		Event occlusion conditions					
		e1	e2	e3	e4	e5	t3
Racquet (%r)	Experts	65.46	66.13	66.13	66.41	68.52	68.74
	Novices	63.24	64.26	66.35	65.23	65.41	64.85
Shuttle outflight (%s)	Experts	0.00	0.00	0.00	0.00	0.00	0.06
	Novices	0.00	0.00	0.00	0.00	0.00	0.00
Trunk (%t)	Experts	4.81	3.79	4.77	3.24	3.34	4.87
	Novices	6.38	6.58	5.55	6.14	6.40	7.68
Head (%h)	Experts	5.06	5.26	4.20	7.66	4.86	6.45
	Novices	10.18	10.28	9.22	9.68	8.09	10.95
Feet (%f)	Experts	1.39	1.29	0.55	0.89	1.07	2.39
	Novices	0.98	0.60	1.09	0.45	0.99	3.00
Screen centre (%x)	Experts	19.00	17.53	18.11	17.57	17.42	11.60
	Novices	17.42	15.62	15.57	18.04	16.37	9.50
Not determinable (%n)	Experts	4.61	6.24	6.94	5.69	6.06	5.89
	Novices	1.80	2.80	2.48	2.50	2.73	4.02

tially modify the search pattern and the presentation of the event occlusion conditions in random order prevents any search modifications from being prepared in advance. The rigid nature of the search patterns elicited suggests that the search sequence may be controlled by some overriding perceptual framework (perhaps like the 'feature-ring' for recognition proposed by Noton and Stark (1971) or some more global equivalent, e.g., Groner et al. (1984)), which acts to pre-set and constrain the order and location of the fixations within the search pattern. Fast moving sections of the display (such as the racquet approaching contact with the shuttle), for example, may automatically attract visual fixation although this appears unlikely to be the sole determinant of the search sequence. [5]

[5] This explanation, for example, cannot account for why the lower body is not fixated with greater frequency early in the search sequence when it is the most fast moving of the segments nor can it account for observations in other studies (e.g., Neumaier 1982) of fixations on relatively static parts of the display in preference to more rapidly moving segments.

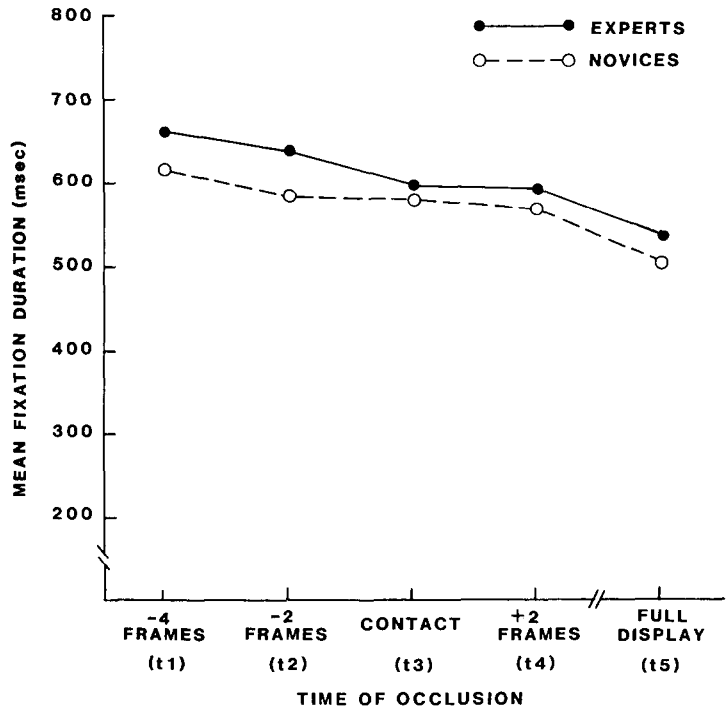

Fig. 6. Mean fixation duration as a function of expertise and the degree of temporal occlusion.

Search rate characteristics

Mean fixation duration

Fig. 6 plots $\overline{FD}$ [6] as a function of the temporal occlusion conditions provided within the film task. No significant skill group differences in search rate were apparent ($F(1,29) = 0.686$, $p > 0.05$) but there were differences in $\overline{FD}$ across the different temporal occlusion conditions ($F(4,116) = 33.247$, $p < 0.05$). Specifically the Newman-Keuls analysis revealed that there was a systematic reduction in $\overline{FD}$ as more display information become available to the subjects, with only the temporal increment from t3 to t4 failing to induce a significant decrease in $\overline{FD}$ ($p > 0.05$). A possible explanation of this effect is that fixations in the early part of the stroke sequence are relatively lengthy because they are

[6] $\overline{FD}$ is actually the inverse of the search rate.

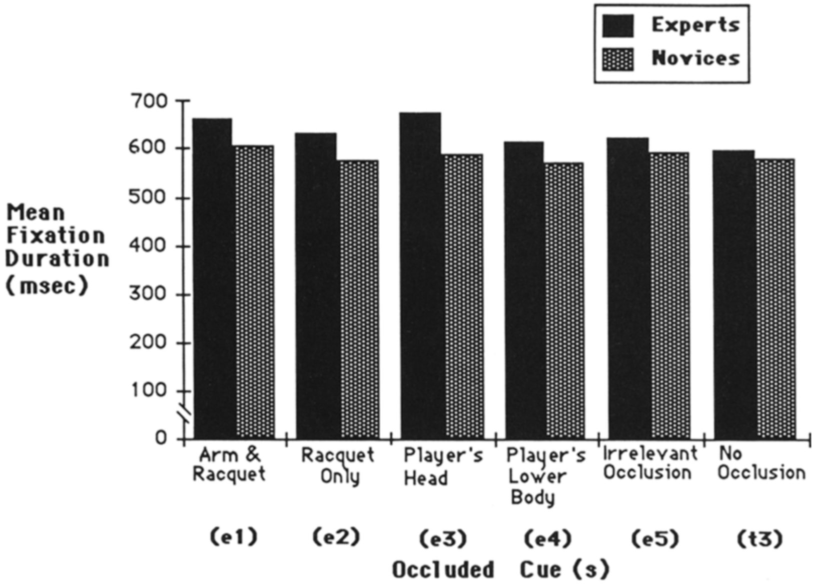

Fig. 7. Mean fixation duration as a function of expertise and event occlusion.

used for the active extraction of information of use in resolving display uncertainty. As more display information becomes available (as in the conditions t4 and t5) the search task becomes more one of confirming the existing information rather than extracting new information and this confirmation can apparently be accomplished through the use of fixations of shorter mean duration. Search rate in this instance therefore appears to reflect quite closely task difficulty and the extent of display redundancy – an effect which has been hypothesized (e.g., Just and Carpenter 1976) but often not demonstrated in visual search studies in which only simple, alphanumeric displays are utilized (cf. Nattkemper and Prinz 1984).

When the task difficulty is altered by masking visibility to specific spatial rather than temporal cues $\overline{FD}$ is again found to be affected ($F(4,116) = 4.408$, $p < 0.05$) but in a common manner for both the expert and novice performers ($F(1,29) = 1.022$, $p > 0.05$) (See fig. 7). The manipulation of task difficulty through event occlusion means, however, apparently exerts a less powerful influence upon $\overline{FD}$ than does the comparable temporal occlusion manipulations.

The notion that $\overline{FD}$ reflects task difficulty is supported by comparisons between the $\overline{FD}$ for this task and other applied visual search tasks

Table 10
Comparison of mean fixation durations ($\overline{FD}$s) across some different visual search tasks.

Search task	Study	Approximate $\overline{FD}$
Tasks using static stimuli		
Reading	Andriesson and de Voogd (1973)	200
Visual inspection	Schoonard et al. (1973) Megaw and Richardson (1979)	< 400
Inspection of CRT displays	Sperandio and Bouju (1983)	400–500 (mode)
Decision-making in sport	Bard and Fleury (1976) Haase and Mayer (1978)	250–300 300 (n)–420 (e)
Tasks using dynamic stimuli		
Helicopter control	Stern and Bynum (1970)	715 (e)–909 (n)
Car driving	Cohen (1978)	410 (on road)–520 (in lab)
Competitive fencing	Bard et al. (1981)	615 (e)–850 (n)

Note: (e) indicates expert subjects, (n) indicates novice subjects.

reported in the literature (table 10). Although differences in $\overline{FD}$ between studies may arise erroneously due to differences in such factors as the sensitivity of the eye movement recording instrumentation for the detection of micro-saccades (Ohtani 1977) and the means by which fixations are defined (Moffitt 1980; Widdel 1984), the available data tentatively suggest that the $\overline{FD}$ for this task of approximately 590 msec is within the range reported for tasks using dynamic stimuli (cf. Stern and Bynum 1970; Bard et al. 1981) but is substantially longer than that generally seen in tasks where the display is static (cf. Bard and Fleury 1976; Yarbus 1967). Across studies the altered task difficulty created by the use of dynamic rather than static displays appears to force the viewers to use correspondingly longer $\overline{FD}$s.

Any effect of task difficulty upon search rate does not, however, appear to extend to comparisons between experts and novices performing the same task. Expert performers do not use shorter $\overline{FD}$s than novices in viewing a particular display (as might be predicted if $\overline{FD}$ was sensitive to relative task difficulty) but rather tend to use longer $\overline{FD}$s (and hence slower search rates) in searching the display. Although experts do show a systematically longer $\overline{FD}$ than novices across all 10 occlusion conditions, in keeping with the notion of a direct search rate–display uncertainty relationship (after Teichner and Krebs 1974), the effect is not a significant one ($F(1,29) = 0.926$, $p > 0.05$). Similarly, no significant differences in search rate between experts and novices are obtained if the number of fixations rather than $\overline{FD}$ is compared, either for the temporal ($F(1,29) = 3.123$, $p > 0.05$) or the event ($F(1,29) = 0.704$, $p > 0.05$) occlusion trials. Given the large range of skill group differences and the sample sizes used in this study one is therefore forced to conclude, contrary to some of the earlier small-group sport (e.g., Bard and Fleury 1976; Bard et al. 1980; Haase and Mayer 1978) and ergonomic (e.g., Papin et al. 1984) studies, that visual search rate is neither a fundamental cause nor indicator of the performance capability differences between experts and novices. These search rate analyses therefore support the earlier ones on fixation location and sequence in indicating that experts may be identified from novices not so much by the nature of the search strategy they use, but rather by their ability to extract relevant information from fixated display items.

Fixation duration distributions

The distribution of the durations of all fixations made by the expert and novice performers are presented in figs. 8 and 9, respectively. Again it is apparent from these plots that experts, on average, use longer fixations than novices in viewing the display but also how the extent of the *FD* variability within the groups acts to prevent this effect from being a statistically significant one. For both skill groups the *FD* distribution is positively skewed with a greater proportion of relatively short *FD*s than fixations of above average duration. This positive skew in the *FD* distributions appears to characterize visual search activity for all manner of tasks and for all levels of performers (cf. Schoonard et al. 1973: fig. 2; Megaw and Richardson 1979: fig. 1; Bouma 1978: fig. 11) and results in a positive correlation emerging between the distribution means and standard deviations (Megaw and Richardson 1979). [7] This positively skewed distribution holds in the current case across all temporal and event occlusion conditions and across different fixation locations with the modal point predictably

[7] The observed distribution characteristics are those of a logarithmically derived function and consequently when a logarithmic rather than a linear abscissa is used the *FD* distributions of both skill groups can be made to approach normality. Specifically the skewness and kurtosis indices can be made to approach zero and the positive mean: standard deviation correlation can be suppressed.

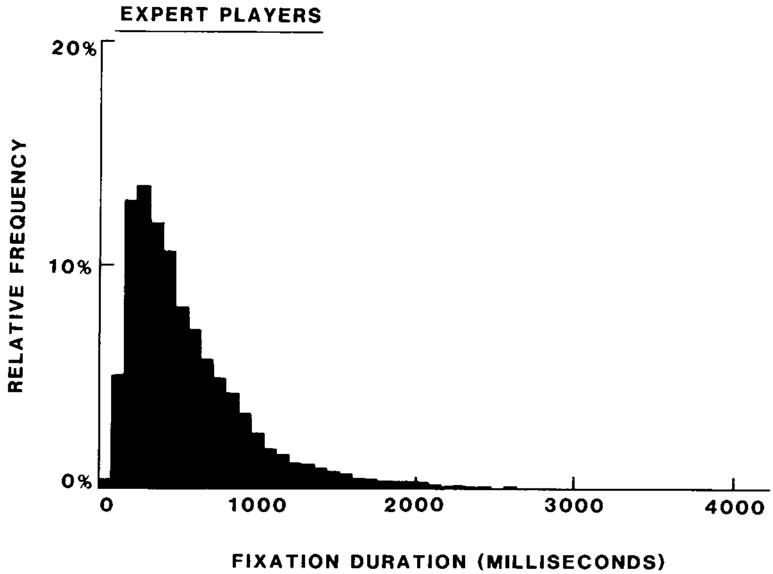

Fig. 8. The distribution of fixation durations for the expert group. The distribution, based on 15,241 separate fixations, has a skew of +1.834 and a kurtosis of 4.845.

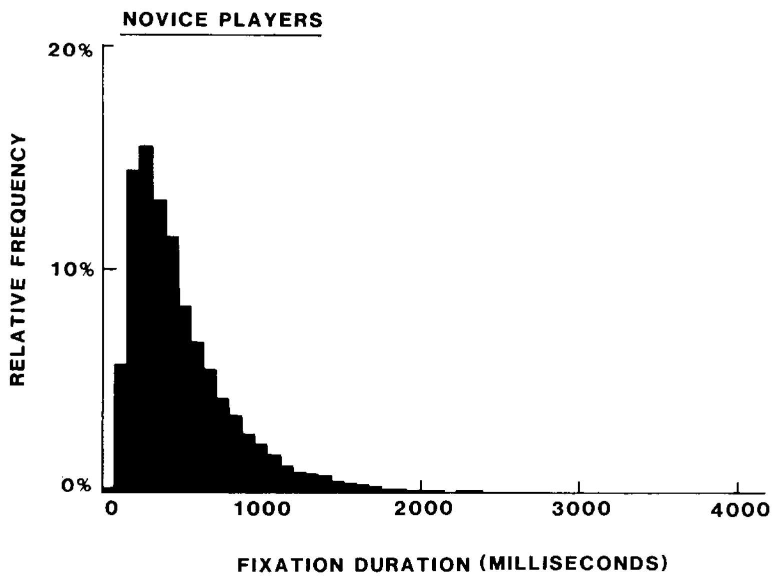

Fig. 9. The distribution of fixation durations for the novice group. The distribution, based on 18,471 separate fixations, has a skew of +1.773 and a kurtosis of 4.487.

being displaced to the right for the more difficult film task conditions and for the more frequently utilized fixation locations (viz. the racquet region).

Search initiation and completion speed characteristics

The parameters of VCT (which reflects the minimal time required to initiate the first saccade in response to the film display appearance) and DT (which reflects the extent to which foveation continues on the viewing screen after the film display has been occluded) provide information regarding the speed with which visual search is both initiated and completed. Visual correction time was measured to examine the hypothesis that experts and novices may vary with respect to their relative speeds of initiating the search sequence. Dwell time was measured to examine the possibility that the extent of the dwell on the screen after film occlusion might be indicative of the subject's response uncertainty and, in turn, of their level of expertise.

Visual correction time

Fig. 10 presents the visual correction times (VCTs) for both the expert and novice groups for each of the five temporal occlusion conditions. Although the expert subjects display more rapid VCTs than those displayed by the novices across all the temporal occlusion conditions, neither these differences in subject proficiency ($F(1,29) = 2.224$, $p > 0.05$) nor the occlusion conditions ($F(4,116) = 1.435$, $p > 0.05$) significantly influence the time taken to make the first saccadic response to the display. Similarly VCT for the event occlusion conditions is also apparently not influenced by the subject's badminton playing capability ($F(1,29) = 0.102$, $p > 0.05$) nor the specific cue occlusion induced ($F(4,116) = 2.213$, $p > 0.05$), as one would expect given the a priori nature of this measure. The magnitudes of the VCTs observed suggest that this delay in commencing the initial saccadic movement represents a typical simple reaction time delay and this concurs with the high eye movement latency–reaction time correlations which have been reported for other selective eye–head coordination tasks (e.g., Yoshimoto et al. 1982). Viewed in this light the observation of systematically, but not significantly, faster VCTs for the expert performers may be as expected (cf. Yandell and Spirduso 1981). The relatively low variabilities observed in the VCTs also support the notion of this

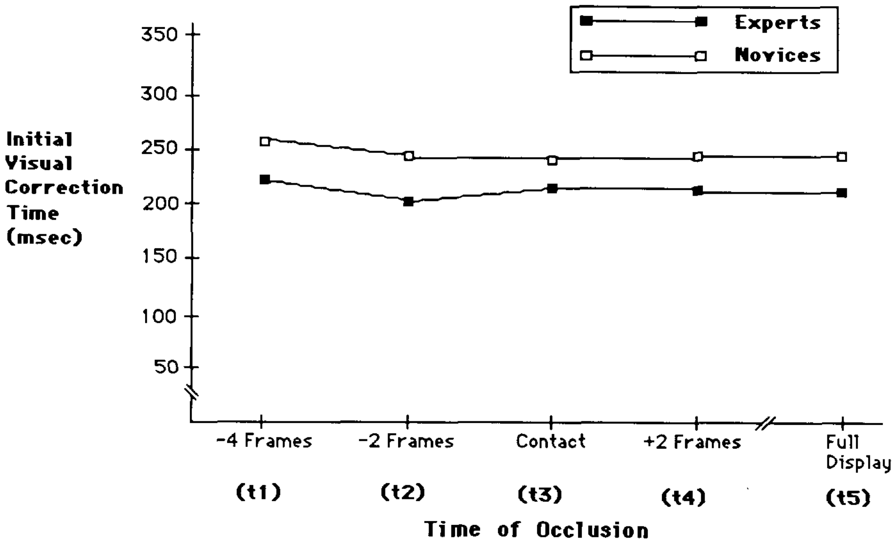

Fig. 10. Visual correction time as a function of expertise and the degree of temporal occlusion.

parameter being a reflection of an inbuilt (or 'hardware') constraint within the visual system.

Dwell time

In contrast to the VCT parameter, dwell time (DT) can be shown to be dependent upon the temporal occlusion task which is presented to the subjects ($F(4,116) = 547.048$, $p < 0.05$), although independent of the skill level of the subject ($F(1,29) = 0.738$, $p > 0.05$) (see fig. 11). Specifically, with each successive gain in temporal information provided by adjacent temporal occlusion conditions there is a significant reduction in DT to the point, in condition t5, where the eye actually leaves the screen prior to occlusion of the film display. This therefore suggest that there is some reasonably direct relationship between DT and the apparent task difficulty. This relationship also persists across the different event occlusion conditions ($F(4,116) = 18.647$, $p < 0.05$) with greatest DTs being apparent on those trials which were completed with the greatest prediction error i.e., e1, where the arm and racquet were occluded and e2, where visibility to the racquet alone was masked (fig. 12). More lengthy mean DTs were apparent for the novices under all five event occlusion conditions (indeed as was the case for the temporal occlusion manipulation) but again these differences failed to

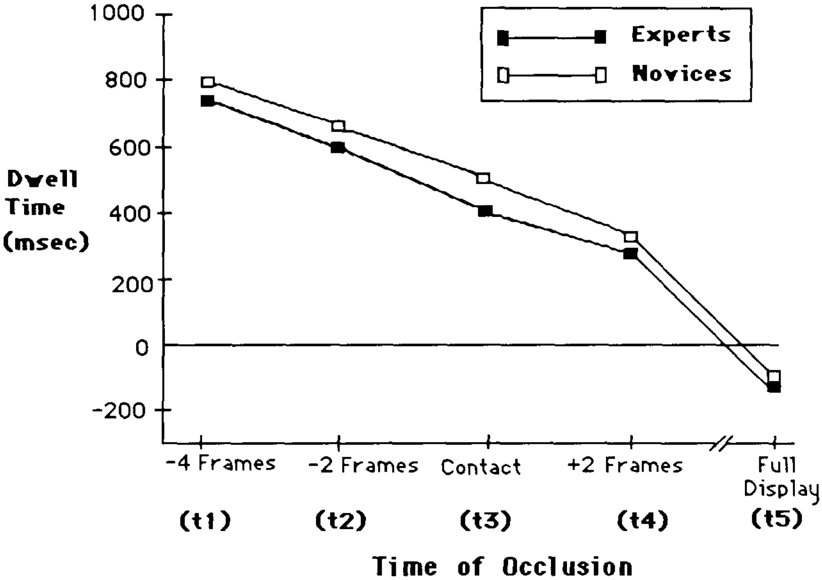

Fig. 11. Dwell time as a function of expertise and the degree of temporal occlusion.

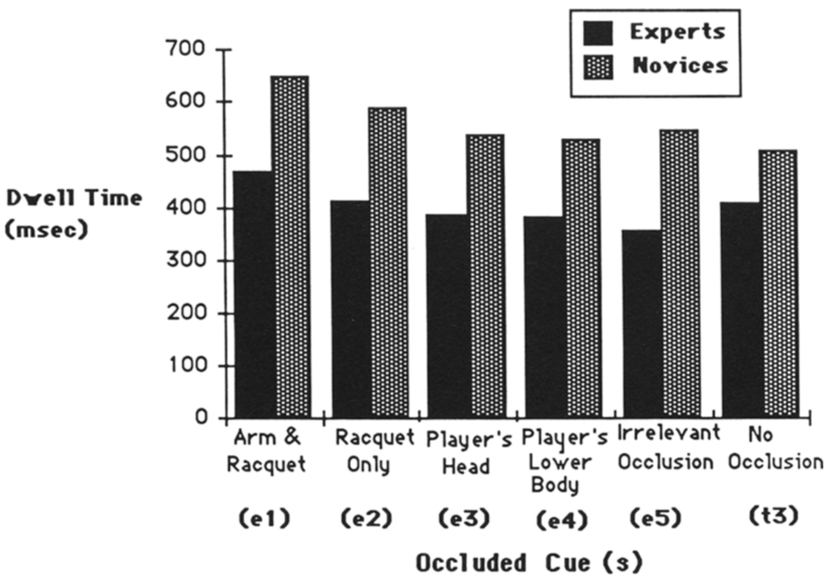

Fig. 12. Dwell time as a function of expertise and event occlusion.

reach acceptable statistical levels ($F(1,29) = 3.649$, $p = 0.063$). It appears, therefore, that all subjects, when faced with a difficult task condition elect to maintain their visual orientation on the screen for quite lengthy periods after the film occlusion in an attempt to utilize all of the available iconic persistence to enhance their stroke prediction.

Summary and conclusions

In this paper the visual search strategies used in the sport of badminton have been detailed in terms of fixation location, sequence and duration characteristics for samples of both expert and novice players. Although experts and novices were found to be clearly different with respect to their ability to extract early information from the display (fig. 1) and with respect to their ability to utilize the arm as a source of anticipatory information (figs. 2 and 3), players from both skill levels were nevertheless found to visually search the display in an essentially similar manner. No substantial differences in the allocation of fixations to display regions (figs. 4 and 5), in search order (tables 1–7), or in search rate (figs. 6 and 7) were evident as a function of player expertise demonstrating clear discrepancies between selective information pick-up, and visual search, as implied from foveal orientation to the display. What appears crucial in discriminating the perceptual performance of the expert from the novice is therefore not so much how the display is overtly searched in order to input information but rather what use the performers can subsequently make of this available environmental information. In this respect our data support the observations of Kundel et al. (1984) on radiology that 'search, at least in its mechanical definition, appear(s) to be less important as a source of error than recognition or decision processes'. Specifically, in the current context, only expert players appear to have the necessary awareness of the critical relationship between key display features to be able to utilize advance information received from the movement of the opposing player's arm although this basic information is equally accessible to the novice. Close parallels therefore emerge with some of the existing statements made regarding skill in the more cognitive activity of chess, such as Neisser's (1976: 180) observation that

> 'One of the characteristics of a good chess player is his skill in picking up relevant information from the board... The information that specifies the proper move is as available in the light sampled by the baby as by the master, but only the master is equipped to pick it up.'

This distinction between visual orientation and information pick-up has important implications both experimentally and practically. Experimentally there are clear inadequacies in using eye movement recording or simple visual search analyses by themselves in an attempt to gain information regarding the performer's information pick-up or processing strategies. As exemplified with the stimuli used in the current study, there is a clear need to also include more direct measures of information extraction and cue dependence (such as event occlusion) to isolate strategies in the perception rather than merely in the reception of display information. In this respect the temporal and spatial manipulations of the display characteristics used here appear to have advantages over the simple behavioral measures of performance, such as decision time, which have been used in conjunction with previous visual search studies of sport (e.g., Bard and Fleury 1976; Tyldesley et al. 1982).

In practical terms it becomes apparent that one should not expect to be able to bring the perceptual performance (and anticipatory skills) of a novice player to the level of an expert merely by forcing them to adopt a perceptual strategy which mirrors that of the expert i.e., in the case of badminton, by teaching the novice player to foveate more on the opposing player's arm action. Modeling of the expert's perceptual strategy per se is unlikely to be a successful means of enhancing perceptual performance (cf. Papin 1984; Papin et al. 1984) unless, in this case, the relationship between arm and racquet action and the subsequent stroke direction and speed can be learnt, and some facility is afforded for concomitant development of the knowledge base upon which the expert's perceptual strategy is based. In this respect the development of training regimes which, in addition to using the search patterns of experts as a prototype, also include anticipatory tasks (like the film occlusion tasks described by Haskins (1965) or Burroughs (1984)) or which draw attention to the key display characteristics governing the emergent kinematics of the arm and racquet action (cf. Williams 1984, 1986), appear to offer potentially the most fruitful avenues for pedagogical gains.

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