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# Are visual cue masking and removal techniques equivalent for studying perceptual skills in sport?

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**Abstract.** The spatial-occlusion paradigm makes use of two techniques (masking and removing visual cues) to provide information about the anticipatory cues used by viewers. The visual scene resulting from the removal technique appears to be incongruous, but the assumed equivalence of these two techniques is spreading. The present study was designed to address this issue by combining eye-movement recording with the two types of occlusion (removal versus masking) in a tennis serve – return task. Response accuracy and decision onsets were analysed. The results indicated that subjects had longer reaction times under the removal condition, with an identical proportion of correct responses. Also, the removal technique caused the subjects to rely on atypical search patterns. Our findings suggest that, when the removal technique was used, viewers were unable to systematically count on stored memories to help them accomplish the interception task. The persistent failure to question some of the assumptions about the removal technique in applied visual research is highlighted, and suggestions for continued use of the masking technique are advanced.

## 1 Introduction

Vision obviously plays a crucial role in athletes' pick-up of environmental information for spatial positioning, balance optimisation, and the planning and adaptive modification of action. In interception tasks, it has been well documented that skilled athletes make rapid and accurate predictions based on early detection and interpretation of visual cues extracted from the opponent's stroke motions (Abernethy and Russell 1987a, 1987b; Goulet et al 1989; Abernethy 1990; Williams and Davids 1998; Williams et al 1999). The basic conclusion has been that these athletes must possess a visual system endowed with superior capacities. But expert/novice comparisons of 'hardware' components such as visual acuity, depth perception, colour vision, ocular muscle balance, and peripheral range did not reveal a significant amount of variance (Starkes and Deakin 1984). Since no particular sensorial equipment was characterised as a potential source of superiority, research became focused on athletes' visual-search strategies to explain the differences in perceptual performance between experts and novices. The underlying assumption of these studies was that eye movements serve as a window into cognitive processes and thus yield information on strategic activities (Henderson 2003). The term visual search is used to describe the process of directing visual attention to locate relevant environmental cues (Magill 2007). Cognitivist theories of perception postulate that visual search can be determined by task-specific knowledge structures stored in long-term memory (Bruce et al 1996). These structures are built up through learning and experience, and are then used to interpret events encountered in similar circumstances. According to Marr (1982), these knowledge structures are used by observers to direct their visual search to the more pertinent or informative areas of a display. Eye movements are controlled by a search strategy that enables the performer to make more efficient use of the time available for analysing the environment. Visual search processes can be assessed by two measurement methods: the direct method and what has been elsewhere termed the 'indirect measurement of visual search' (Cauraugh and Janelle 2002).

The experimental methods of direct measurement consist of using apparatuses such as the eye-tracker to record eye movements, usually with the help of the corneal reflection technique. With this technique, the researcher knows both where a person is looking at any given time and the sequence in which the eyes are shifting from one location to another (for a review, see Collewijn 1999). Eye trackers have been used to investigate perception in soccer (Williams and Davids 1998; Savelsbergh et al 2002), tennis (Goulet et al 1989; Singer et al 1996), basketball (Vickers 1996), volleyball (Vickers and Adolphe 1997), gymnastics (Bard et al 1980), ice hockey (Bard and Fleury 1981), golf (Vickers 1992), baseball (Bahill and Laritz 1984), table tennis (Ripoll and Fleurance 1988), and boxing (Ripoll et al 1995). The evidence indicates that the visual-search patterns of expert performers can be characterised by fewer fixations of longer duration before decision-making. Making fewer fixations of longer duration is considered effective, because the sensitivity of the visual system is greatly reduced during saccades. This expert visual behaviour creates a more coherent perceptual representation of the environment by avoiding the harmful effects of saccadic suppression (Volkmann 1962), which is typical of many fixations of brief duration (Helsen and Pauwels 1993). In other words, experts have lower search rates (defined by the number and duration of fixations) and more efficient visual-search strategies. Early eye-movement recordings showed that a subject's fixations centred on interesting or informative areas of an image, leaving blank or uniform regions uninspected (Buswell 1935). Fixation positions are not random, with fixations clustering on informative regions.

The experimental methods known as 'indirect measurements' make use of the temporal- and/or spatial-occlusion paradigm of the visual scene. The occlusion approach involves filming the appropriate display from the athlete's customary perspective and offers the possibility of determining differences in cue dependence between participants. The temporal-occlusion paradigm requires players to observe video sequences that are occluded at a number of specific points, typically several frames before or after the moment at which the opponent produces a stroke. After the video clip has been occluded, the players indicate the opponent's future actions or the direction in which they believe the ball will go. The spatial-occlusion paradigm has been employed to investigate the nature of the anticipatory cues the performer uses in the anticipation process. The methodology involves presenting subjects with video sports sequences while selectively occluding specific cue sources, typically but not necessarily for the entire duration of the trial. According to Shim et al (2005), the spatial occlusion technique may be a "more viable" (page 188) method than eye tracking for investigating experts' perceptual skills, because attention can shift without an eye movement. This technique has thus been used in a number of sports, such as badminton (Abernethy and Russell 1987a, 1987b), squash (Abernethy 1990), and football (Williams and Davids 1998), to demonstrate the effect of cue occlusion on the prediction of ball trajectories. In these studies, the determination of the relevant visual cues was established logically. The assumption was that removal of the most important sources of information would result in the greatest decrement of performance in comparison with the full-display condition. Müller et al (2006) specified that, if prediction error increased when a particular part was blacked out, it meant that this part not only had to be providing a great deal of useful information to the anticipator, but also that the information conveyed by this cue was unique and could not be provided effectively or concurrently from another unoccluded source. As highlighted by Janelle and Hillman (2003), the results obtained in eye-tracking studies are generally consistent with occlusion findings.

In all the above-mentioned studies that use the spatial-occlusion technique, visual-perceptual space was occluded by applying opaque boxes over the presentation. But, since 2006, several studies have used a new screen-off manner that renders the athlete's equipment and/or body segments 'invisible' (Müller et al 2006; Williams et al 2006;

Jackson and Mogan 2007). With the use of this new spatial-occlusion form, Jackson and Mogan (2007) examined the advance information sources that tennis players use to judge serve direction. The skilled group suffered the largest drop in performance in the conditions of ball occlusion and arm + racket occlusion. Earlier experiments in racket activities that used traditional occlusion techniques have presented rather consistent results. In their second experiment, Abernethy and Russell (1987a) showed that masking the visibility of the racket plus the arm holding it caused significant decrements in prediction accuracy for all participants. Abernethy (1990) also demonstrated that visual information about the opponent's arm and racket is critical for accurate anticipation. This being the case, it is surprising that an analysis of the three most recent studies (Müller et al 2006; Williams et al 2006; Jackson and Mogan 2007) reveals no theoretical questioning about the repercussions of using the screen-off spatial-occlusion form. Moreover, it appears that the equivalence of these two occlusion forms is tacitly assumed (Williams et al 2006), even though they can be distinguished by the amount of information they offer. In fact, regarding the older occlusion form, Williams and Ericsson (2005) pointed out that:

> "The disadvantage with these techniques was that it was often possible to pick out the outline of the obstructed cue by focusing on the movement of the opaque mat or box over time." (page 292)

It is thus possible to follow the masked cues. The new occlusion form differs radically in the sense that the cues are no longer masked but become 'invisible'. Erasing the visual scene from each frame of the video clip causes the areas that are behind the player to emerge, making it impossible to follow the hidden cue. The viewers perceive only the background of the visual scene. For these various presentations, the observers must resolve problems related to the choice of relevant information. They need to correctly interpret the presented information while taking into consideration the task demands, their experience, and their response repertory, and they need to do so promptly because rapid decision-making and execution are critical to success in sports. With such complexity, observers must use all the knowledge previously acquired about the task to facilitate and enhance their exploration (Henderson and Hollingworth 1999). However, making a response based on absent cues rather than masked cues amounts to a modification in the task. As the information to collect for the two experimental methodologies differs, athletes' cognitive activity while preparing a response is likely to differ as well. Collectively, these lines of evidence suggest that problems remain to be solved before further experiments are carried out. As suggested by Jackson and Mogan (2007):

> "Because of the unusual nature of images formed with the cloning [ie removal] technique, researchers could clearly benefit from combining the spatial occlusion paradigm with the analysis of point of gaze so that they can understand better how image manipulations affect visual search behaviour." (page 349)

In an effort to clarify the issues surrounding the use of a new spatial-occlusion form, we assessed in the present study the equivalence of the two spatial-occlusion methodologies. Specifically, we used eye-movement recordings to compare these two spatial-occlusion forms within the framework of perceptual – motor tasks.

The serve – return task in tennis was chosen to explore this issue, since it is a well-documented natural task that makes sense. The findings from several studies of eye fixations while performing this task suggest that experts focus on central body regions like the head – shoulders and trunk – hip to collect information concerning the ball's likely destination, while novices tend to fixate on more distal and potentially less relevant cues such as the ball and racket (Williams et al 2002). Goulet et al (1989) found that all players focused on the ball during the preparation phase of the serve whereas, during the execution phase, experts fixed their eyes more on the racket and arm than did novices, who focused only on the ball. In addition, Singer et al (1998) showed during the ball-toss phase that the less skilled groups (intermediate players) favoured a strategy using an anticipatory saccade to place the point of gaze in front of the ball. This finding indicated that the ball is a major area for information extraction for novice to intermediate players. Taking these studies into account, we analysed the visual-search patterns of tennis players preparing to return a serve and confronted with two spatial-occlusion forms applied to the ball region—an important focal point for these athletes. The experimental device involved two film clips: a mask-occlusion clip (the box form) and a background-occlusion clip (the invisible form). We assumed that the characteristics of the visual-search strategies would provide the basis for evaluating the representativeness of the knowledge produced by research using the new occlusion form. Regarding the discrepancies between the two occlusion methodologies, we hypothesised that the spatial-occlusion form would have an effect on visual-search behaviour. Operationally, we expected that: (i) the search rates would differ when the ball was masked and when it was erased, (ii) fixation locations would differ when the ball was masked and when it was erased, and (iii) fixation orders would differ when the ball was masked and when it was erased.

Information, however, has no value outside of the perceptive activity that picks it up and the cognitive activity that processes it in view of response preparation. In order to measure a spatial-occlusion effect on visual behaviour, a contextualised task first needed to be constructed. Reaction times were also recorded in order to make the experimental task meaningful. In sports situations, expected information is automatically processed while unexpected information massively mobilises attention (Ripoll 2004). Since being unable to focus on the ball-toss trajectory disrupts observers' expectations, our second hypothesis was that reaction times would be longer with background occlusion than with mask occlusion because the observers would be deprived of the movement outline of this informative cue.

Last, because using the reaction times made sense only in terms of the prediction rate and as a means to ensure the ecological validity of the study, an analysis of the decisional performances was executed. We expected that success rates would be dependent on the extent of the informative deterioration and therefore predicted that success would be higher for mask occlusion than background occlusion.

## 2 Method

### 2.1 *Participants*

Twenty male tennis players volunteered to participate in the study. The subjects ranged in age from 18 to 22 years (mean age $= 20.2 \pm 1.4$ years) and were recruited from the students of the School of Sports, Rouen University, France. Because the determination of whether an object has violated a physical constraint usually requires knowledge of the identity and semantic attributes of that object (Henderson 1992), the participants had to possess perceptual knowledge about the tennis serve–return task. Thus, in order to avoid difficulties in understanding the scene, the minimal qualification for study entry was possession of a French Tennis Federation ranking. All the subjects were contained within a six-level ranking range and played an average of 10 to 15 matches per year. However, none of them played at a high level (according to the definition of Ericsson et al 1993). All had normal or corrected-to-normal vision and were naive with respect to the hypotheses under investigation. Before taking part in the study, the subjects were told that they were free to withdraw at any time. The ethical considerations and principles of the World Medical Association Declaration of Helsinki regarding experimentation were respected.

### 2.2 *Task*

Visual-search strategies were examined using film-based simulations of tennis serves. A two-choice prediction task was developed in which the subjects were required to judge whether the player was serving down the centre of the court or wide into the service box. The subjects were told to prepare to return a series of serves as fast as possible. The task provided the opportunity to analyse the various areas of interest, the nature of the responses, and the reaction times of the subjects.

### 2.3 *Test film*

The film was prepared with two digital video cameras (Panasonic NV-DS38EG) recording at 25 Hz and positioned in the receiver's court. The barycentres of the tripod-mounted cameras were located 1.15 m from the baseline, and 0.80 m and 1.02 m from the single sideline, at a height of 1.25 m. The first camera was used to record a wide-angle shot of the server and the service box, during which time the second camera recorded a tight shot of the server. This filming position was chosen to best simulate the viewing position of the receiving tennis player.

Two right-handed tennis players were chosen to create the test stimuli based on their ability to exhibit correct service technique and a level of play similar to that of the participants. The two players were required to produce flat services, as they would do in normal competition, from the deuce side into the diagonally opposite service box in two different directions: down the centre of the court and wide. Four legal strokes with clear trajectories were selected for inclusion in the film task. These four strokes consisted of two strokes per server, one for each direction. The experimental task was then constructed to present these four original events in two different types of test films.

The selected clips were digitised and edited with Adobe Premiere (Version 6.0) software. For all the service sequences, the wide shot and the tight shot were mixed in such a way that the tight shot was seen up to ball/racket impact and then the wide shot was seen until the end of the sequence. To ensure that ball location was unchanged by the switch in these two shots, the images from the two cameras were cropped. Each trial included the preparation phase of the server, all the actions of the service motion, and the entire ball flight. The two test films comprised 12 clips, randomly ordered, in which each sequence was repeated three times (1 occlusion condition $\times$ 2 servers $\times$ 2 directions $\times$ 3 repetitions). The order of presentation of all trials was strictly identical for the two experimental films.

In the first experimental 'mask-occlusion film', the four original services were each presented to the subjects after video manipulation to mask the server's ball. Visibility of the ball was prevented throughout each trial by placing an opaque patch in all frames of the clip (see figure 1).

The second experimental 'background-occlusion film' required another form of image manipulation to achieve spatial occlusion. Instead of applying an opaque patch on the image surface, parts of the visual scene were literally erased from each action frame (see figure 1). As for the first experimental clip, the server's ball was removed from the clip. To do so, the video clips were digitised and edited with Adobe Premiere (Version 6.0) software in order to obtain all the frames. The spatial occlusion was achieved with Adobe Photo Deluxe (Version 4.0) software by superimposing two images: one that contained the tennis-court scene but not the server, and one that contained the tennis-court scene and the server. This organisation allowed us to erase one region of the first image to see the background of the second and enabled the foreground to be replaced with the background. When the erasing was done, the individual frames were collected with Adobe Premiere software to create the occluded clips.

No auditory information was presented for either of the experimental films. An intertrial interval of 5 s was built into the film construction.

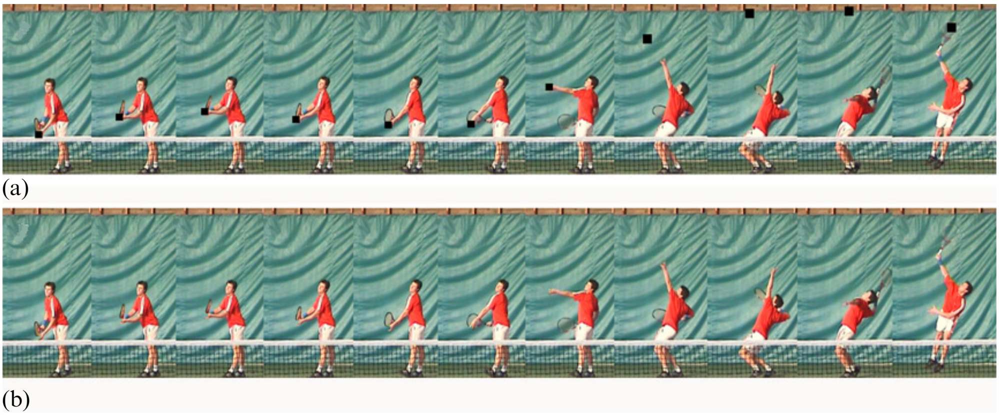

**Figure 1.** [In colour online, see http://dx.doi.org/10.1068/p6828] Examples of final frames from the displays presented in the experiment under each of the spatial-occlusion conditions. Frames (a) illustrate the 'mask-occlusion' technique. Frames (b) illustrate the 'background-occlusion' technique.

### 2.4 *Apparatus*

The stimuli were video-projected on a large screen to create a 4 m × 3 m image positioned approximately 10 m from the participant. The participants' response movements were recorded with a timer positioned on a table just in front of them. Two keys were dedicated to the two directions they could encounter: one key for 'left', one for 'right'. The timer was connected to a DV video tape recorder to collect the data on the nature of the responses and the decision-making time.

Eye movements were recorded with an eye-tracking system (ASL Model D6; Applied Science Laboratories, Waltham, MA) that recorded gaze direction with an accuracy of 0.5°. This desk-mounted monocular system had a sampling capability of 50 Hz. The eye camera provided an infra-red image of the eye and enabled the collection of displacement data between the pupil and the corneal reflex. This information was used to compute the visual point of gaze. The eye-movement recorder was calibrated using a simple nine-point reference grid so that the fixation mark corresponded precisely to the subject's point of gaze. The data were collected with GazeTracker software (Eye Response Technologies, Charlottesville, VA, USA). Gaze position (indicated by crosshairs) was superimposed over the scene camera image and recorded with 25-Hz frame-by-frame playback. Fixation locations were defined by comparing the point-of-gaze cursor with the coordinates obtained via the GazeTracker (Eye Response Technologies, USA) program.

### 2.5 *Procedure*

The subjects were initially informed about the nature and response requirements of the task. Specifically, they were told that they would view clips of tennis players serving from the receiver's perspective and that their task was to make a prediction about the ensuing direction of the stroke. They were then seated in front of a large screen, with one hand resting on the left key and the other on the right key of the timer. They were instructed to predict the probable direction of the service as soon as possible. A response was required on all trials, even if the subject was completely uncertain. After the instruction procedure, the observer was told to place his chin in a chin-rest that was used to maintain the viewing position. All stated that the chin-rest was comfortable and did not disrupt views of the stimuli. Before data collection, the eye-tracker system was calibrated to ensure that it was registering the point of gaze as accurately as possible. The calibration procedure was performed before each observation of the two experimental films and when necessary. The film task was then presented by projecting the constructed film at eye level. All subjects watched the two test films in the order: (i) 'mask-occlusion' (MO) and then (ii) 'background occlusion' (BO). This order was established so as to avoid confronting the subjects during the first trials of the experiment with a scene in which they were unable to function naturally because the relationships between cues of the natural setting were not preserved in the BO film. Conversely, the MO was presented first because this display is known as a contextually relevant task design. By respecting this order, we ensured that the visual-search strategies were not deconstructed from the beginning of the experiment, as no semantic inappropriateness was contained in the display. Thus, this order offered the opportunity to compare in an adequate manner the visual strategies across conditions: when subjects were kept under unambiguous processing and when they were not. Practice trials had been held earlier to ensure familiarisation with the experimental setting. The practice film presented the occlusion conditions and the two service trajectories to the subjects. These sequences were performed by a third right-handed server who took part in the original filming. The subjects rested for 5 min between the two test films. The entire study session was completed in about 30 min.

### 2.6 *Dependent variables and data analysis*

#### 2.6.1 *Decision-making data*

*Decision onset*: This was defined as the time from ball/racket impact to the subject's key press.

*Correct responses*: The number of trials in which the key pressed corresponded to the correct side was also recorded.

2.6.2 *Visual search data.* Eye-movement analysis was restricted to the preparation and stroke phases of the service. This restriction was established to prevent eye-movement recordings during ball flight. Thus, the eye movements that were monitored reflected a strategic activity of information extraction to predict the direction of the stroke and not a simple observation of the ball that was being stroked. The part of the sequence that was taken into consideration ranged from the elevation of the server's arms to ball/racket impact.

*Search rate*: This measure included the mean number of fixations and the mean fixation duration per trial. It was expressed as the percentage of time fixated in relation to the time tracked per sequence. A fixation was operationally defined as the period of time during which the eye remained stationary for at least three frames (120 ms).

*Percentage of viewing time*: This measure referred to the percentage of total viewing time that the subjects spent fixating each area of the display when looking at the stimuli. Only the time fixated per sequence was taken into account and thus the sum of all the percentages of time fixated for each region did not amount to 100%. Ocular fixations for each trial were described in terms of both their location and duration characteristics. The display was divided into discrete zones and fixations into each of these zones were recorded using the following codes:

H: fixations on the server's head;
T: fixations on the server's trunk;
R: fixations on the server's racket;
B: fixations on the ball;
AR: fixations on the arm holding the racket;
AB: fixations on the arm holding the ball;
F: fixations on the server's feet and lower body;
BP: fixations on the area in which the ball toss will occur;
IP: fixations on the area in which the ball/racket impact will occur;
N: fixations to other unnamed features of the display.

### 2.6.3 *Statistical analysis*

Initial examination of the decision-making results revealed that a high number of subjects performed with a reactive response mode despite the experimenter's instructions: decision onsets often occurred after the ball/racket impact. Therefore, as a first step in the data analysis, we examined whether the decision onset for each subject was before or after the rebound of the ball in the service box. The reaction-time data were thus converted to non-numerical data (nominal value). The statistical analysis was performed with a one-sample $\chi^2$ test. Our initial idea was to classify the subjects on the basis of their reaction times, but the majority of them touched the key after the ball rebound. On the basis of both the temporal properties of the responses (the one-sample $\chi^2$ test was performed for each subject to determine individual response profiles), and the similar level of task involvement for all subjects, the subjects were pooled into one group to better focus on behaviours generated by the task context.

The possible differences in the impact of the two occlusion techniques on decision onset and correct response variables were analysed with a $\chi^2$ test for independence (for $2 \times 2$ tables with Yate's correction when needed). To do so, the proportion of correct and incorrect responses was calculated for each trial and all subjects, as well as the proportion of trials in which the key was pressed before and after the ball bounce.

The eye movements during each trial were analysed to determine the fixation number and duration in order to describe the visual strategy in terms of search rate. To facilitate the comparisons between the three identical sequences, we calculated a mean value for each dependent variable. If the eye tracker lost track of eye position during a sequence, the sequence was eliminated. This accounted for 3.7% of the data. Fixation number, duration, and search rate were analysed with 2 (occlusion type: MO, BO) $\times$ 2 (server type: A, E) $\times$ 2 (direction type: T, W) repeated-measures analyses of variance (ANOVAs).

To establish the percentage of viewing time, repeated-measures ANOVAs were performed according to a 2 (occlusion type: MO, BO) $\times$ 2 (server type: A, E) $\times$ 2 (direction type: T, W) $\times$ 10 (location: H, T, R, B, AR, AB, F, BP, IP, N) factorial design.

Concerning the search order, initial analyses were performed descriptively using a series of transition matrices on each trial. Unlike the usual methods reported in the literature, and having in mind the incongruous display of the experiment, all the possible exchanges ($10 \times 10 = 100$) were taken into account and collected. Then an average search order corresponding to the total of one subject's exchanges through all the films was employed as a statistical measure for each subject. Therefore, search-order analysis was computed without considering the serve or direction type. Of the 100 possible exchanges, the analysis was limited to the favoured transitions according to the following procedures. To start with, all exchanges that presented zero values ($n = 24$) were eliminated. Next, exchanges that presented a number under the equiprobable quantity corresponding to the sum of all exchanges were ruled out ($n = 54$). Last, exchanges that represented 5% or less of the total number of exchanges were excluded. In line with Goulet's classic study (1989), a three-way ANOVA was performed, with occlusion type (2) and favoured exchanges (6) as the within-participants factors, and the average frequency with which a combination of successive fixation locations was observed as the dependent measure.

All statistical tests were completed with $\alpha$ set at 0.05. We conducted Mauchly's test of sphericity to determine whether the sphericity assumption was violated. In cases of violation, we used the Greenhouse–Geisser correction to adjust the degrees of freedom. We conducted a-posteriori comparisons to follow up significant effects using Tukey's honestly significant-difference (HSD) procedure. Effect sizes (reported as Cohen's $d$ values) were calculated to further compare significant differences (using pooled standard deviation for comparison of two conditions).

## 3 Results

### 3.1 *Decision-making data*

As expected, the test showed significant differences on decision onsets ($\chi_1^2 = 4.03$, $p = 0.04$) with a greater proportion of responses after the ball rebound in the BO condition. Effect-size calculation yielded a $d$ value of 0.18. No significant occlusion effect on response accuracy was observed ($\chi_1^2 = 3.36$, $p = 0.07$).

### 3.2 *Visual search data*

*Mean fixation number*: Analysis of variance revealed a significant main effect for server type ($F_{1,19} = 3.07$, $p = 0.007$). No significant difference was found between MO and BO in the average number of fixations per second. No other main effect or interaction effect was observed. Inspection of the data revealed that subjects averaged $3.32 \pm 0.17$ fixations $s^{-1}$ with server A, whereas an average of $3.04 \pm 0.15$ fixations $s^{-1}$ was performed with server E.

*Mean fixation duration*: Analysis of variance showed that the duration of fixation was not related to the type of occlusion ($F_{1,19} = 0.74$, $p = 0.401$), type of server ($F_{1,19} = 2.32$, $p = 0.144$), or direction ($F_{1,19} = 2.73$, $p = 0.115$). No interaction effect was observed. The subjects averaged a fixation duration of $338 \pm 139$ ms per trial.

*Search rate*: Analysis of variance showed that the search rate was not related to the type of occlusion ($F_{1,19} = 0.74$, $p = 0.401$), type of server ($F_{1,19} = 2.32$, $p = 0.144$), or direction ($F_{1,19} = 2.73$, $p = 0.115$). No interaction effect was observed. Participants averaged a search rate of $89.60\% \pm 7.57\%$ per trial (ie the percentage of time fixated in relation to the percentage of time tracked).

*Percentage of viewing time*: Analysis of variance indicated a significant main effect for fixation location ($F_{9,171} = 10.65$, $p < 0.001$). Concerning both spatial occlusion forms, the AB (mean = 19.45%), U (mean = 19.40%), H (mean = 12.29%), and B (mean = 12.02%) regions were the principal areas of fixation, while cues arising from AR (mean = 1.51%) and BP (mean = 1.50%) very rarely attracted direct foveal inspection. After collapsing across the location factor, a-posteriori tests revealed significantly greater time spent fixating on AB (19.45%) and U (19.40%) versus all other zones, with the exception of H (12.30%) and B (12.02%). AB and U did not significantly differ. Conversely, the subjects exhibited a significantly shorter percentage of viewing time on AR (mean = 1.51%) and BP (mean = 1.50%) than on H (12.29%) and B (12.02%). The relative fixation time per location results and $p$ values are shown in table 1. Analysis of variance also revealed interaction effects for server × location ($F_{9,171} = 2.07$, $p = 0.034$), film × service × location ($F_{9,171} = 2.15$, $p = 0.028$), and server × service × location ($F_{9,171} = 4.67$, $p < 0.001$).

**Table 1.** Summary of relative fixation time per area, pair comparisons and $p$ values after collapsing on location factor.

| Location | Location | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | H | T | AB | B | IP | N | F | BP | R | AR |
| Head (H) | | | | | | | | | | |
| Trunk (T) | 0.69567 | | | | | | | | | |
| Arm (ball) (AB) | 0.28396 | *0.00065* | | | | | | | | |
| Ball (B) | 1.00000 | 0.75671 | 0.23381 | | | | | | | |
| Impact prediction (IP) | 0.59156 | 1.00000 | *0.00032* | 0.65836 | | | | | | |
| Unnamed (N) | 0.29381 | *0.00070* | 1.00000 | 0.24256 | *0.00035* | | | | | |
| Lower body (F) | 0.10489 | 0.98974 | *0.00002* | 0.13384 | 0.99676 | *0.00002* | | | | |
| Ball prediction (BP) | *0.00743* | 0.69224 | *0.00001* | *0.01053* | 0.78642 | *0.00001* | 0.99822 | | | |
| Racket (R) | 0.27202 | 0.99979 | *0.00004* | 0.32668 | 0.99998 | *0.00004* | 0.99999 | 0.96702 | | |
| Arm (racket) (AR) | *0.00754* | 0.69502 | *0.00001* | *0.01069* | 0.78882 | *0.00001* | 0.99829 | 1.00000 | 0.96774 | |
| Time fixated/% | 12.29 | 6.90 | 19.45 | 12.02 | 6.47 | 19.40 | 3.89 | 1.50 | 5.07 | 1.51 |

*Search order*: Six favoured exchanges illustrate the visual-search patterns during the experiment: from the head to the arm holding the ball (H $\rightarrow$ AB), from the arm holding the ball to the arm holding the ball (AB $\rightarrow$ AB), from the arm holding the ball to the ball (AB $\rightarrow$ B), from the ball to the ball (B $\rightarrow$ B), from an unnamed feature of the display to the ball (N $\rightarrow$ B), and from an unnamed feature of the display to an unnamed feature of the display (N $\rightarrow$ N). Analysis of variance showed that the effects of both occlusion type ($F_{1,19} = 8.02$, $p = 0.011$) and occlusion type $\times$ exchange type ($F_{5,95} = 4.52$, $p < 0.001$) were significant. A-posteriori tests revealed that the average observation frequency increased significantly from the BO condition ($1.64 \pm 0.27$) to the MO condition ($2.37 \pm 0.26$). After collapsing across occlusion type $\times$ type of exchange factor, the a-posteriori procedure revealed that players under the MO condition used more successive fixations between the ball and the ball (B $\rightarrow$ B, mean = 3.95) than the N $\rightarrow$ N exchange (mean = 1.95). Furthermore, the B $\rightarrow$ B (mean = 3.95) exchange in the MO condition occurred significantly more often than H $\rightarrow$ AB (mean = 1.65), AB $\rightarrow$ AB (mean = 1.35), AB $\rightarrow$ B (mean = 0.95), B $\rightarrow$ B (mean = 1.65), or N $\rightarrow$ B (mean = 1.40) under the BO condition. No other main or interaction effect was observed.

## 4 Discussion

The aim of the present study was to examine the relationship between eye movements and spatial-occlusion techniques to determine whether the two methodologies are equivalent for studying perceptual skills in sport. Since spatial-occlusion methodologies are not defined by the action of masking visual cues (MO) but by removing cues (BO), the visual system needs to be able to infer the previous relationships of the cues from an incomplete representation. We predicted that the spatial-occlusion form would affect visual-search behaviours. To investigate this, we combined the spatial-occlusion paradigm with eye-movement recording. A subsidiary aim was to determine the potential mediating effect of the type of spatial-occlusion methodology on the subject's reaction times and decisional performances.

### 4.1 *Decision-making*

Analysis of the decision-making data revealed that the decision onsets associated with MO scenes differed from those associated with BO scenes by a greater proportion of responses after the ball rebound in the BO condition. Williams and Ericsson (2005) pointed out a potential difference in the nature of the two techniques because of the possibility of picking up the outline of the obstructed cue in the MO condition. Our data confirmed that the available information was not the same across conditions. Indeed, reaction times, which indicate the speed with which the input is processed and the response is prepared, were longer under BO. The difference in visual presentation was enough to produce two scenes computationally different for the subjects. This difference results from the fact that the visual system was able to retrieve knowledge from past memories about the presented scenes only if particular stimuli had already been encountered. Indeed, in the serve–return task, skill is based on the ability to detect and interpret perceptual information through comparison with an internalised memory structure based on past experiences in similar situations (Williams et al 1999). Logan's instance-based model (1988) suggests that every exposure to a stimulus leads to an internalised trace of that stimulus. As more instances are stored, performance improves because more relevant instances can be retrieved and the time required to retrieve them decreases. This increase in task-specific knowledge leads to rapid and efficient retrieval of relevant information as soon as the appropriate stimulus is presented. In our film task, the subjects were immersed in a stimulus-induced race between stored instances (Hommel and Eglau 2002). In the MO condition, the occlusion of the ball implied its existence in the scene, and the possibility of perceiving the movement of the opaque box corresponded to experience with the ball toss and its various response alternatives in a real serve – return task. In the BO condition, the absence of the ball set the subjects before a scene they had never encountered. Consequently, no memory traces of that particular stimulus-response were stored. The subjects were thus unable to 'engage the race' and, lacking information about the stimulus, they showed longer reaction times.

We are well aware that removing information from the ball toss eliminated a potentially critical source of visual information (Goulet et al 1989; Singer et al 1998) and that denying the subjects access to information they normally use is an explanation to consider. However, the effect of the occlusion type on decision onset seems more complex because no difference in the proportion of correct responses was observed across conditions. Yet, in anticipation tasks the length of time available to view the display is allowed to covary with response accuracy (Abernethy 1985; Williams et al 1999). This indicates that the longer reaction times observed in the BO condition were not solely linked to a higher cognitive load induced by a lack of stored instances. In our time-constrained experiment, cues had to be detected, but also interpreted to carry out the anticipation task. The notion of interpretation is closely tied to the referential meaning of objects and the semantic appropriateness of the relations occupied by the objects of the scene being viewed (Biederman et al 1982). In the experimental presentation, the BO scene displays the incongruous coexistence of a server producing ball-toss movements and the absence of the ball that has been tossed up. Thus, a probable explanation for the subjects' decision-making behaviours may be that the highly artificial nature of the display stimulus in conjunction with the absence of the ball may have promoted the scene as incongruous and rendered the subjects incapable of engaging in unambiguous stimulus-based processing. This computationally cumbersome factor may explain why the BO success rate equaled that of the MO condition, even though the subjects in the latter condition benefited from extra time by making later decisions. With regard to decision-making, our findings suggest that removing a key perceptual feature may provide viewers with a very different challenge from that presented when an aspect of the visual scene is masked.

### 4.2 *Search rate*

No significant differences were noted across conditions for the mean number of fixations or the mean fixation duration. Fixation duration was fairly consistent at about 330 ms. These values are similar to those found in response to familiar situations in decision-making in sports (300 ms: Haase and Mayer 1978; 351 ms: Helsen and Starkes 1999). If search rate is an indicator of the information-processing load (Just and Carpenter 1976), and it increases when complexity or uncertainty is added to a display (Bard and Fleury 1981), this result suggests that using the BO technique placed no greater demand on the subjects. However, contradictory findings in search rate have frequently been reported in both ergonomics and sports research, notably because of a lack of systematic time constraints imposed on performers and the absence of dependent measures of task-response accuracy (for further details, see Abernethy 1988 or, more recently, Williams et al 1999). Therefore, the similar search rates across conditions in this study were probably due to the fact that no body cues were occluded in the test films. In a recent study by Mecheri et al (submitted), conducted to assess the level of incongruity conveyed by the BO technique, removal of the server's head provoked a compensation strategy for dealing with the increased cognitive demands, with more fixations of shorter durations compared with head masking. The absence of the head is enough to constitute an incongruous scene because it violates the spatial relations among the server's body parts, thereby invalidates knowledge activated by the context category, and is accomplished by removing a key feature of the scene. In the present investigation, the spatial occlusions, even with the BO technique, did not impair the valuable information provided about the meaningful relationships among the server's body parts, which were essential to correctly interpret the display. Thus, in the scene task, the server, who was the main element of the experimental scene, was in normal relation to his setting. The most expected relationships between the tennis server and his setting were thus not violated and the scene was unaffected by strong semantic violation. Although the ball was not visible in the BO sequences—a situation not found in natural task environments—the response occurred in a more ecologically based setting and the violation costs (in reference to the violation concept of Biederman et al 1982) of the display were few. Because natural access to the visual gist was possible, knowledge about its category was activated, and visual body cues could be matched to internal knowledge about the service stroke motions. The main effect of server type on the number of fixations corroborated this explanation. The fact that the subjects were able to adapt their visual fixation functions to the server irrespective of condition indicated that the interaction between knowledge in long-term memory and the activation of this knowledge through perceptual processes was not disrupted by the removal technique. Such adaptation to particular types of service movements requires effective perception of domain-specific visual scenes.

### 4.3 *Percentage viewing time*

The same features (in particular the arm holding the ball, unnamed, the head and the ball) attracted the majority of fixations in both conditions. Some basic studies have also demonstrated the importance of these visual cues in the tennis serve – return task (Williams et al 2002). Because the classic areas of the display were fixated, this implies that the visual search strategy employed under BO also relied on familiarity-based judgments. Although the BO technique removed an important perceptual variable that intermediate performers use to guide their decisions, it did not significantly disturb the particular regions fixated. Through experience with the task, the subjects likely learned the optimal location for picking up the information they needed (Hayhoe et al 2007) under severe time constraints. They thus directed their gaze to the classic body regions used at their level of expertise in the anticipation task of the tennis serve – return.

### 4.4 *Search order*

The experiment revealed a difference between the occlusion conditions with respect to the visual-search patterns. First, the analysis of search-order data showed a significant effect of the type of exchange on the number of ocular fixations. This result is chiefly explained by the fact that the $B \rightarrow B$ exchange under MO condition was the most frequent exchange whatever the occlusion condition. In other words, viewers under MO strongly organised their search around the ball positions by using a sequence of ocular fixations on the ball-toss trajectory. Consequently, this combination of a high number of successive fixations from one ball location to the next ball location under MO led to a significant difference in the average exchange frequency across conditions. Second, a-posteriori comparisons of the interaction effect of occlusion type $\times$ type of exchange revealed that under MO the subjects alternated their gaze between the ball and the ball significantly more frequently than all other types of exchange in BO with the exception of the $N \rightarrow N$ transition. As expected, being deprived of the movement outline of the occluded ball under BO deeply modified the connections between cues. Moreover, although the following differences were not significant, the two most important variations in the percentage of viewing time across conditions concerned the time fixated on B, which nearly doubled from 8.62% in BO to 15.41% in MO (note that, when a fixation occurred on the location of the ball-toss trajectory under BO, this fixation was attributed to the B zone) and the percentage of time fixated on H, which changed from 15.46% in BO to 9.12% in MO. Given these observations, and the fact that the B → B exchange under MO occurred significantly more often than all the exchanges encountered in BO, except one which did not include the ball, it seems reasonable to argue that the successive combination of fixations on the ball, which was lost in the BO condition, may have been transposed to the server's head and face in this condition. In fact, the preceding findings suggest two different profiles across occlusion forms. In the MO condition, the subjects produced linear patterns involving fixations on body cues followed by a combination of successive fixations on the ball location, while in the BO condition they developed a more circular pattern by turning back the clock on the head when the ball was tossed up after they had foveated the body cues. The latter strategy matches with the observation that in the serve – return task performers react to the unexpected absence of the ball toss by relying on a nearby point that is also a critical source of information (Goulet et al 1989; Singer et al 1996). In contrast, viewers under MO could couple the onset of their decisions with the pick-up of essential information from the ball.

### 4.5 *Removal versus masking techniques: Equivalence or not?*

Overall, the findings from the present experiment provide evidence that the background technique carried bias. First, the BO scene presented subjects with a novel decision-making task, given that it is the continued practice with the same stimulus that leads to the storage of increasingly more information about the stimulus and its alternatives (Logan 1988). The absence of stored instances in memory about this particular task imposed stimulus-based processing and thus led to longer reaction times. In addition, the ambiguous display of a server who is performing a ball toss without a ball was highly inappropriate and caused semantic violations (Biederman et al 1982) that did not allow the subjects to unambiguously process what they were seeing. The second problem was that, as a function of the temporal phases of the scene, the subjects were not systematically able to count on the retrieval of contextual memory traces. At the beginning of the serve, the relevant cues were contained in the server's body, which was in normal relation to its setting. For this reason, the viewers were able to adopt similar search rates, located their fixations in similar locations across conditions, and were even able to adapt their visual fixations on the basis of which server they were viewing. However, once the ball was tossed up, they were unable to count on stored instances until the end of the monitoring sequence. This inability to access past memories about the interceptive task implies that, in a second phase of the serve, the subjects relied solely on bottom – up processing. Because such processing is driven by incoming stimuli and the ball is a mobile source of critical information, the subjects adopted different scanpaths for each spatial-occlusion form. Therefore, the dynamic description of visual behaviour under BO was different from the behaviour in the semantically well-formed scene.

## 5 Conclusion

Rather than presenting results on expertise-based perceptual difference using film occlusion displays, our results suggest that recent studies may have underestimated the importance of the choice of the spatial-occlusion form for the study of visual perceptual skills. Our results revealed that the BO methodology leads to difficulties in the theoretical understanding of anticipation as a cognitive process, because it does not allow clear relationships to be drawn between the specific visual cues used and the anticipatory performance that is established. It should be kept in mind that spatial-occlusion measures do not directly assess perceptual skills; they enable inferences to be drawn about what skilled athletes attend to when tackling actual problems or plausible simulations within their specialist domain. With respect to this concept, the test film should not present anything with a low probability of appearing in the scene, given the rest of the scene and the observer's past history. The expectations in interceptive actions are important for optimising experience-based effects to accurately reflect the full nature of visual perceptual skills (Mann et al 2010). Experiments that apply the recent extension of the spatial-occlusion technique to this framework increase the difficulty of determining whether changes in performance are due to the removal of a contextual cue, a disruption in the spatial and temporal relationships between regions caused by cue removal, or the anomalous scene context that is created. Methodologically, this issue casts doubts on the possibility of developing valid measures of perceptual-cognitive skills and effectively capturing subject behaviours in the laboratory or field setting. The scene task should allow for precise measurements, so that performance can be objectively evaluated. An important point emphasised throughout this study has been that perceptual skills must be assessed in meaningful situations, wherein athletes are allowed to function naturally in a contextually relevant task design.

Finally, Williams and Ericsson (2005) stated that the possibility of picking out the outline of an obstructed cue by focusing on the movement of an opaque box is a 'disadvantage'. A result that was not highlighted in the classic spatial-occlusion study of Abernethy and Russell (1987b) is that the distribution of fixations was essentially uninfluenced by manipulation of the film display. For all five regions that could be masked, the eyes still fixated a single region for the same viewing time even though the information in that region was masked. In other words, the masking technique has demonstrated its usefulness for making controlled comparisons of cue usage without causing the subject to elicit atypical search patterns, while the removal technique in the present study resulted in systematic changes in search-pattern characteristics. This observation puts the notion of 'disadvantage' into perspective, because masking visual cues instead of eliminating them may provide greater insight into the cognitive processes involved in interception tasks. This is particularly important regarding the methodological challenge of developing suitable performance measures for perceptual-cognitive expertise. It is widely acknowledged that highly skilled tennis players are more attuned to the natural task constraints than are less skilled players (Müller and Abernethy 2006). Moreover, an important attribute of the expert is the ability to chunk visual information into meaningful associations rather than compilations of individual items (Helsen and Starkes 1999). Chunks act as pre-compiled perceptual elements that can be rapidly recalled and assembled into a rich representation of a situation (Ericsson and Chase 1982). Without a match, experts must investigate more environmental cues, which requires attention and occupies working memory. The removal technique could thus potentially fail to accurately reflect the true nature of perceptual-cognitive skills. In this sense, removing cues from the experimental scene may result in important components of expertise being eliminated and the representativeness of the generated knowledge is thus called into question.

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