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The contributions of central and peripheral vision to expertise in basketball: How blur helps to provide a clearer picture

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Abstract

The main purpose of this study was to examine the relative roles of central and peripheral vision when performing a dynamic forced-choice task. We did so by using a gaze-contingent display with different levels of blur in an effort to (i) test the limit of visual resolution necessary for information pick-up in each of these sectors of the visual field, and as a result, to (ii) develop a more natural means of gaze-contingent display using a blurred central or peripheral visual field. The expert advantage seen in usual whole field visual presentation persists despite surprisingly high levels of impairment to central or peripheral vision. Consistent with the well-established central/peripheral differences in sensitivity to spatial frequency, high levels of blur did not prevent better-than-chance performance by skilled players when peripheral information was blurred, but did impact response accuracy when impairing central vision. Blur was found to always alter the pattern of eye movements before it decreased task performance. The evidence accumulated across the four experiments provides new insights into a number of key questions surrounding the role that different sectors of the visual field play in expertise in dynamic, time-constrained tasks.

Keywords: gaze-contingent display, decision-making, central vision, peripheral vision, expertise

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In dynamic visually-guided tasks such as driving a car, flying a plane, and playing sport, the role of peripheral vision is often overlooked but plays a crucial role in guiding behaviour. For example when driving, if an eminent hazard is evident in the periphery, the driver first detects the hazard using their peripheral vision and then re-directs their central gaze towards it (Crundall, Underwood, & Chapman, 1999). Because of the putative significance of peripheral vision in dynamic tasks, it has long been assumed that skilled performers might have some form of superiority in their ability to pick-up information using their visual periphery. In particular, this might in part be because they are better able to account for central task demands, and as a result, are able to adequately account for information in their peripheral vision (Underwood, Crundall, & Chapman, 2008; Weltman & Egstrom, 1966). In contrast, novices may require more attentional resources to concentrate on the unfamiliar information in their central vision, and as a result may have little attentional capacity to attend to the peripheral information (Parker, 1981).

Much of what is currently known about central and peripheral vision is based on studies that measure the direction of visual gaze. In these studies gaze is typically recorded to provide an inference of what visual information is relied upon when performing the task. Studies of this nature typically (though not exclusively) find systematic differences in the visual search pattern of skilled and lesser-skilled performers (for reviews see, Abernethy, 1988; Land, 2006). There are, though, two fundamental problems in using the direction of central vision to make inferences about the roles of central and peripheral vision in information pick-up. First, the line-of-gaze may not necessarily equate to where the observer's attention is directed, as it might equally, at any instant, be directed towards any part of the *peripheral* visual field (Ripoll, 1991). The second problem is that even if a performer's attention is aligned centrally, the fact that gaze is directed towards any given location cannot in itself guarantee that relevant information has been 'picked-up' to benefit task performance. There are numerous examples of stark expert-novice differences in information extraction where the gaze behaviours of the different skill groups are largely indistinguishable (e.g., Abernethy & Russell, 1987; Helsen & Pauwels, 1992). The inability of conventional gaze studies to account for potential information pick-up from peripheral vision is a substantial limitation and this – coupled with the absence of alternate methods of assessing peripheral vision use in everyday tasks – means that expert-novice differences in the use of peripheral vision remain largely untested (Davids, 1984).

Screen-based *gaze-contingent displays* that change content depending on where an observer is looking provide one potential means of differentiating the roles of central and peripheral vision. Gaze-contingent displays dynamically alter the information visible to participants depending on where the participant is fixating at that given moment in time. The technique permits the creation of conditions in which vision can be restricted to, for example, either only a limited eccentricity around the line of gaze (creating a 'moving window' that presents only central vision), or, only vision *outside* this central field (creating a 'moving mask' that presents only peripheral information) (McConkie & Rayner, 1975; Rayner & Bertera, 1979). In the moving window condition any information pick-up must originate from central vision as the line of gaze and the information available for pick-up are aligned, whereas in the moving mask condition information pick-up must be from information located *away* from the line-of-gaze. To-date, gaze contingent displays have been used to differentiate the roles of central and peripheral vision across a wide range of different *static tasks*, that is, tasks in which the display does not change. For example, the technique has been used to great effect to examine skill in reading (Rayner, 1975; Rayner, Inhoff, Morrison, Slowiaczek, & Bertera, 1981), showing that central vision is used during the early part of fixations to identify words whereas peripheral information is used later in the fixation to select a target for the next saccade.

Recent technological advances now allow the gaze-contingent technique to be applied to dynamic video displays where the visual array is continuously changing and tasks can be performed under rather strict time constraints. Ryu, Abernethy, Mann, Poolton and Gorman (2013) recently used a gaze-contingent display to examine the complementary roles of central and peripheral vision when skilled and less-skilled basketball players performed a fast-paced decision-making[1] task. Participants viewed video stimuli representative of situations encountered in basketball games and made decisions about the most appropriate action to take when the video footage occluded at a critical moment in the play. The results showed that the skilled players had an advantage for information extraction that held irrespective of whether they were using central and/or peripheral vision. The results of the study did, however, also reinforce a crucial point about the dual-role of peripheral vision in dynamic tasks, that is, it is used not only to *pick-up* information, but also to *localise* other features to guide future eye movements (e.g., Findlay, 1982; Nuthmann, 2014; Ripoll, 1991). When peripheral vision was completely removed by using opaque (i.e., black) occlusion, not only was peripheral information pick-up impaired, but participants altered their search strategy because they were also unable to localise other display features. Because opaque occlusion was used it was not possible to determine whether the changes in gaze were a result of restrictions to information pick-up or because participants were unable to see the information necessary to localise features used to guide their next fixation(s).

[1] The term *decision-making* in the field of expertise refers to the ability to choose the most appropriate response when faced with a variety of different possible options. We avoid the use of the term here to avoid confusion with the wider psychological literature on decision-making.

A common approach in studies using gaze contingent displays is to use a blurred rather than a fully opaque (black) imposition to the visual field in order to preserve the information necessary for the guidance of eye movements while still impairing information pick-up. For this to be successful, the threshold level of peripheral blur necessary to impair information pick-up should be less than that necessary to alter gaze. However, it is not at all clear whether this is actually the case. For instance, Loschky and McConkie (2000) presented a moving window using peripheral blur when viewing static images and found that the extent of the visual search was influenced by a lower level of blur than was performance on the task. That is, the threshold level of blur necessary to impair information pick-up was *higher* than that needed to alter gaze. A growing number of studies have shown that blur actively constrains attentional selection and as a result readily changes gaze. Loschky et al. (2014) have recently argued that blur pre-attentatively guides attentional selection, and consistent with this idea, gaze tends to be drawn towards clear rather than blurred regions of an image (e.g., Enns & MacDonald, 2013; Loschky & McConkie, 2002; Nuthmann, 2014; Reingold & Loschky, 2002). In particular, blur attenuates the size of saccades: a clear moving window surrounded by a blurred periphery leads to smaller saccades (e.g., Loschky & McConkie, 2000, 2002; Nuthmann, 2014), while central blur with a clear surround increases the size of saccades (Cornelissen, Bruin, & Kooijman, 2005; Nuthmann, 2014). Fixation durations on the other hand tend to increase irrespective of whether the blur is central or peripheral (Bertera & Rayner, 2000; Loschky & McConkie, 2000, 2002; Nuthmann, 2014; though see Miellet, Zhou, He, Rodger, & Caldara, 2010), a finding that most likely reflects an increase in the difficulty in planning the next saccade (Cornelissen et al., 2005).

Collectively these studies suggest that as the quality of visual input decreases, gaze will be altered before peripheral information pick-up decreases. However, existing studies rely largely on the presentation of *static* images and it is not clear whether this relationship will hold when viewing *dynamic* scenes. In fact, there is good reason to suspect that blur will influence the perception of dynamic stimuli in a manner that is quite different to the way it influences the perception of static images. First, the inherent blurring that is already apparent for a fast moving stimulus as it moves across the retina can influence the perception of clarity (Burr & Morgan, 1997) and may alter the way that information pick-up and eye movement selection is controlled. Second, recent studies of perceptual-motor expertise have rather intriguingly suggested that performance in dynamic tasks can be extremely resistant to, or even *improve*, as a result of blur. For instance, motor task performance is highly resistant to blur when driving (e.g., Higgins, Wood, & Tait, 1998) and when hitting moving targets (e.g., Mann, Abernethy, & Farrow, 2010a, 2010b; Mann, Ho, De Souza, Watson, & Taylor, 2007), and blur has been found to *improve* performance when the predicting the outcome of action sequences (Jackson, Abernethy, & Wernhart, 2009; Mann et al., 2010b). It seems reasonable to expect that for dynamic stimuli, blur might interact with vision in a different manner to that seen when the images are static.

The main purpose of the studies reported in this paper was to examine the relative roles of central and peripheral vision when viewing a dynamic visual stimulus. In doing so, to disentangle the two key roles of peripheral vision we sought to establish whether *information pick-up* or *eye movement guidance* would be preserved when the quality of the visual input was decreased using blur. While it is possible that a gradual increase in blur will eventually decrease task performance while keeping the pattern of gaze unchanged, it is possible that the two key roles of peripheral vision are so inextricably linked that changes to the quality of peripheral vision may lead to changes in gaze behaviour before decreasing task performance.

Experiment 1

In Experiment 1, we sought to partially replicate the gaze-contingent study by Ryu et al. (2013). The opaque (black) occlusion used in that study resulted in clear changes in the gaze behaviour of participants that may have been attributable to their inability to localise peripheral display features. As a result, in Experiment 1 we used three levels of blur in addition to opaque occlusion and applied it to both the *moving window* and *moving mask* displays. In line with the results of the Ryu et al. (2013) study, we hypothesized that skilled participants would demonstrate more accurate and faster responses in the forced-choice task irrespective of whether vision was available across the whole visual field or selectively to only the central or peripheral sectors of the field. Importantly, we sought to establish whether peripheral information pick-up would be influenced by a lower threshold level of blur than would eye movement guidance.

Method

Participants

Nineteen skilled male basketball players (*M* age = 23.4, *SD* = 4.1; *M* playing experience = 11 years, *SD* = 2.4; all were guards in the top tier of their University League) and 19 less-skilled players (*M* age = 22.4, *SD* = 4.0; *M* playing experience = 1.9 years, *SD* = 2.0; recreational players only) took part in the experiment. In all experiments reported here, participants had normal or corrected-to-normal vision and provided informed consent prior to commencing the study. Ethical approval was obtained from the institutional human research ethics committee.

Apparatus

An Eyelink II (SR Research Ltd., Mississauga, ON) was used to record the eye movements of participants and to control the gaze-contingent display. To record eye movement data, we relied on the monocular corneal reflection from the participants’ dominant eye using a sampling rate of 250 Hz. Using this system the delay between an eye movement and the repositioning of the gaze contingent display on the screen was on average 16 ms (range 12-20 ms). This display-change latency is well below the 80 ms latency shown to be necessary to detect blur in gaze contingent displays (Loschky & Wolverton, 2007). The system was calibrated by asking participants to fixate on targets in a 9-point reference grid and then validated in the same manner (acceptable error to < 0.5°). Calibration was repeated if the error at any given point was > 1°, or if the average error for all points was > 0.5°. Eye movement data were analysed using Data Viewer software (SR Research Ltd., Mississauga, ON).

Test Materials

The dynamic visual stimuli were video clips of five-on-five basketball play (see Gorman, Abernethy, & Farrow, 2012, 2013). The video footage was filmed from a raised platform at the half-court position so that all players and all markings on one half of the court were visible. The film was edited so that clips ended at the moment the ball-carrier would be required to make a critical decision. In the previous study by Ryu et al. (2013), participants were required to decide whether the player with the ball was best placed to pass the ball or to 'drive' the ball towards the basket. It is possible that participants could have generated high response accuracies for the pass-or-drive decision if they simply followed the heuristic that 'if a teammate sets a screen[2], then I should drive to the basket'. It is possible, indeed probable, that the more skilled players may have been more aware of the potential to apply the heuristic(s) and, if they chose to so do, might provide a plausible explanation for their performance advantage across all the viewing conditions. To address this potential concern, the task for Experiment 1 was altered to a four-choice one in which a decision was required on each trial as to which of the four teammates was best positioned to receive a pass. Three expert coaches (each with over 40 years of coaching, and

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[2] A 'screen' takes place when an offensive player stands stationary in a position on the court that impedes the movement of an opposing player attempting to defend an attacking teammate.

national or international coaching experience) collectively viewed the video clips to ensure that each clip was representative of actual game play and to adjudge the most appropriate decision. Only those clips in which the coaches were in complete agreement were used in the experiment.

For the purpose of introducing visual blur, three levels of a low-pass Gaussian filter were applied to the video footage using Adobe Premiere CS 4 (Adobe Systems Incorporated, San Jose, CA): 20 units for the low, 50 for the moderate and 100 for the high blur conditions. This method applies Gaussian blur to each pixel where the radius of the Gaussian kernel equates to 5.4, 14.1, and 26.6 pixels and as a result the videos were filtered with a spatial frequency cut-off of 1.0, 0.5, and 0.3 cycles per degree respectively (based on 50% attenuation of the amplitude in the frequency domain). These blur levels were chosen on the basis of pilot testing to select levels of blur that were expected to have no, moderate, and a severe impact on task performance.

Experiment Builder software (SR Research Ltd., Mississauga, ON) facilitated the gaze-contingent presentation of the video clips. Nine different viewing conditions were presented (see Figure 1). In the *full clear* control condition, the normal, un-manipulated display was presented. In four *moving window* conditions, a clear moving circular window of 2.5° radius was generated about the point of fixation, with peripheral vision degraded using either a low, moderate, or high blur filter, or a black opaque mask. Bertera and Rayner (2000) established that a window of 2.5° radius represents the size of the visual span in a search task, that is, the minimum window size at which performance is not impaired. We adopted this size window as it ensured that the window included the fovea (≈ 1° radius; Polyak, 1941) while not being so large that it occluded all of the useful information in our task. In the four *moving mask* conditions, central vision was degraded by applying a low, moderate, or high blur filter, or a black mask, to the circular window of 2.5° radius about the point of fixation while the periphery remained clear. The same eight video clips were used for each of the nine viewing conditions to ensure that performance in each condition could be effectively compared while keeping the trial numbers to a manageable level. The experimental test film therefore consisted of a total of 72 trials (8 video clips × 9 viewing conditions) that all participants viewed in the same randomized order.

INSERT FIGURE 1 ABOUT HERE

Procedure

Participants were seated 60 cm from the Eyelink II display monitor. The horizontal and vertical extents of the monitor subtended 30 × 24° of visual angle respectively (screen size = 338 × 270 mm). Prior to each trial a black fixation target was presented at the centre of the display. The participant fixated this target and the gaze position measured during the fixation was used to correct any post-calibration drift. Each video clip ran for 7 s, and 3 s after it occluded a static response slide was shown to participants for 5 s. A common challenge in studies of this type is to ensure that participants are able to unambiguously communicate their decision to the experimenter. In studies employing video displays, this is often achieved by using a response image that shows the final video frame seen prior to occlusion of the video (Mann, Farrow, Shuttleworth, & Hopwood, 2009; Raab & Johnson, 2004, 2007). This approach ensures that participants can unambiguously select, in this case, the exact player they chose to be the correct decision. We were concerned though that, by doing so in this experiment, we would be inadvertently providing participants with additional information that may not have been available to them when the central or peripheral visual field was occluded (the gaze contingent manipulations were not present when participants viewed the response slide). As a result, we chose to use response slides that were based on the final frame of the video clip, but we employed three specific modifications (see Figure 1j for an example). First, all defensive players were digitally removed (using Adobe Photoshop CS 4) to prevent the proximity of the defender and attacker from biasing participant responses (an unmarked attacker or distant defender is a key cue to pass to that teammate). Second, the attacking players without the ball were replaced (at exactly the same location) by a standard image of a player standing in a neutral anatomical position to prevent the posture of the teammate from biasing responses. Finally, a numerical label (from 1 to 4) was placed adjacent to the four attacking teammates to ensure that participants could unambiguously communicate their response. Participants were instructed to decide as quickly and as accurately as possible which player was best placed to receive a pass, and to press the corresponding numerical button on a computer game pad (Microsoft Sidewinder Plug and Play; Microsoft, Redmond, WA). Prior to testing participants took part in 18 practice trials (different to those used in the experiment) to familiarise themselves with the test procedure and with the gaze-contingent manipulations of vision. The entire test session took around 60 min.

Dependent Variables and Data Analysis

Performance data. *Response accuracy* was determined by calculating the percentage of trials where the response of the participant matched the response agreed upon by the coaches. *Response time* was the mean time (in ms) that elapsed from the moment the response slide appeared on the screen to the time that the button press response was registered by the computer.

Gaze data. Three dependent variables were computed for analysis. First, the *mean fixation duration* (in ms) was calculated by averaging the duration of all fixations in each video clip. Second, *mean saccadic amplitude* was calculated as the average angular subtense of all saccades in each trial (in degrees of visual angle) to measure the breadth of the search. Third, ten areas of interest were identified to examine differences in the distribution of gaze during a trial: (i) the player in possession of the ball (the ball-carrier), (ii) the defender of the ball-carrier, (iii-

vi) each of the four attacking team-mates (from closest to most distant from the ball-carrier), and (vii-x) the matching defenders of the four attacking team-mates. The areas of interest changed whenever the ball was passed between players to ensure that the ball-carrier always referred to the player in possession of the ball. The location of each area of interest was coded once for every frame of video footage to produce a template that could be used to automatically detect whether the location of gaze coincided with one of the areas of interest. *Percentage of total viewing time* spent viewing each of the ten areas of interest was then calculated for each trial.

Statistical analyses. As the main purpose of Experiment 1 was to isolate the use of central and peripheral visual information while examining for changes in gaze behaviour, we conducted separate analyses of the four *moving window* conditions and the four *moving mask* conditions while including the *full clear* viewing condition as a fifth (control) condition in each analysis. As a result, for the *moving window* and *moving mask* conditions four dependent variables (*response accuracy*, *response time*, *mean fixation duration*, and *mean saccadic amplitude*) were analysed using separate 2 (Skill: skilled, less-skilled) × 5 (Blur: clear, low blur, moderate blur, high blur, opaque) ANOVAs with repeated measures on the second factor. Planned *t*-tests were used to (i) compare performance in each of the blur manipulations to that found in the clear (control) condition, (ii) perform successive comparisons to check for differences between increments in blur, and (iii) determine whether the response accuracy in each condition was significantly different to the 25% level achievable by chance/guessing. The distribution of fixations to the ten areas of interest (*percentage of total viewing time*) were subject to 2 (Skill) × 5 (Blur) × 10 (Area of interest) ANOVAs with repeated measures on the last two factors. In order to check whether there was any learning occurring over the course of the experiment as a consequence of repeated exposure to each of the eight separate video clips, the response accuracy and response time data were subject to a 2 (Skill) × 9 (Clip exposure: 1st, 2nd, 3rd …, 9th presentation) ANOVA with repeated measures on the second factor.[3] In all experiments, effect sizes are reported as partial eta squared values or Cohen's *d*, and a Greenhouse-Geisser correction was applied to the degrees of freedom when the assumption of sphericity was violated. The alpha level for all comparisons was set at $p = .05$.

Results

Response accuracy and response time. In the *moving window* trials (Figure 2a) the skilled players outperformed the less-skilled players irrespective of the level of peripheral blur (main effect for skill, $F(1, 36) = 73.47$, $p < .001$, $\eta_p^2 = .67$). Intriguingly though, when compared to the clear (control) condition the two groups *improved* their response accuracy with some peripheral blur (skill × blur interaction, $F(4, 144) = 2.58$, $p = .04$, $\eta_p^2 = .07$). The response accuracy improved for the skilled players with moderate peripheral blur ($p = .02$, $d = 0.59$), and for the less-skilled players with low peripheral blur ($p = .03$, $d = 0.72$). Skilled players performed above chance levels irrespective of the level of blur (*p*s < .001, *d*s > 3.06), whereas less-skilled players performed above chance levels with low and moderate blur, and with black opaque vision (*p*s < .048, *d*s > 1.00). This is noteworthy given that their accuracy in the clear control condition was only at chance level. In the *moving mask* trials (Figure 2b) the skilled players also performed consistently better than the less-skilled players irrespective of the level of central blur (main effect for skill, $F(1, 36) = 79.52$, $p < .001$, $\eta_p^2 = .69$; no main effect of blur, $F(4, 144) < 1$; no skill × blur interaction, $F(4, 144) < 1$). The skilled players responded at better-than-chance levels irrespective of the amount of blur (all *p*s < .001, *d*s > 3.89) whereas the responses of the

[3] There were no changes in response accuracy (no main effect for exposure, $F(8, 288) = 1.43$, $p = .19$, $\eta_p^2 = .04$, no skill × exposure interaction, $F(8, 288) = 1.72$, $p = .09$, $\eta_p^2 = .05$) or response time (no main effect of exposure, $F(5.05, 181.69) = 1.21$, $p = .31$, $\eta_p^2 = .03$, no skill × exposure interaction, $F(5.05, 181.69) < 1$) as a consequence of repeated exposure to the video clips.

less skilled players were no better than chance for any level of central blur (*p*s > .14, *d*s < 0.72).

INSERT FIGURE 2 ABOUT HERE

In the *moving window* trials (Figure 2c) the skilled players responded quicker than the less-skilled players irrespective of the level of peripheral blur (main effect for skill, $F(1, 36) = 9.39$, $p = .004$, $\eta_p^2 = .21$). Blur significantly altered the response times, though similarly for the two skill groups (main effect for blur, $F(2.52, 90.64) = 26.55$, $p < .001$, $\eta_p^2 = .42$; no skill × blur interaction, $F(2.52, 90.64) = 1.09$, $p = .35$, $\eta_p^2 = .03$). When compared to clear vision, response times were slower when the periphery had moderate blur, high blur, or was black. Response times increased from low to moderate blur ($p < .001$, $d = 0.55$), and from high blur to black peripheral vision ($p < .001$, $d = 0.61$). In the *moving mask* trials (Figure 2d) the skilled players responded faster than the less-skilled players (main effect for skill, $F(1, 36) = 10.85$, $p = .002$, $\eta_p^2 = .23$; main effect for blur, $F(3.21, 115.38) = 7.62$, $p < .001$, $\eta_p^2 = .18$). When compared to the clear condition the response times differed only with black central vision ($p < .001$, $d = 0.59$).

Fixation durations. The level of peripheral blur in the *moving window* trials influenced the duration of fixations (main effect of blur, $F(2.12, 76.26) = 6.19$, $p < .001$, $\eta_p^2 = .18$), with the mean duration decreasing with high blur ($p = .028$, $d = 0.42$) and with black occlusion ($p = .004$, $d = 0.58$; see Figure 2e). The fixation duration decreased in each of the progressive comparisons (*p*s < .031, *d*s > 0.20) except between clear and low peripheral blur ($p = .649$, $d = 0.07$). The changes in fixation duration were not mediated by the skill level of participants (no skill x blur interaction, $F(2.12, 76.26) = 1.74$, $p = .18$, $\eta_p^2 = .05$; no main effect of skill, $F(1, 36) < 1$). In the *moving mask* trials (Figure 2f) central blur *increased* the fixation duration with low, moderate, and high blur (*p*s < .044, *d*s > 0.31; main effect for blur, $F(3.03, 109.11) = 15.53$, $p < .001$, $\eta_p^2 = .30$). Successive comparisons revealed significant decreases in the duration of fixations from moderate to high blur and from high blur to black central vision (ps < .005, ds > 0.31). The changes in fixation duration with blur were not mediated by skill (no skill x blur interaction, $F(3.03, 109.11) = 2.02$, $p = .115$, $\eta_p^2 = .05$; no main effect of skill, $F(1, 36) < 1$).

Saccadic amplitude. Saccades became progressively shorter with increasing peripheral blur in the *moving window* trials (Figure 2g; main effect of blur, $F(2.99, 107.67) = 51.61$, $p < .001$, $\eta_p^2 = .59$). The saccadic amplitude decreased across each progression in blur (ps < .041, ds > 0.19) except from low to moderate blur ($p = .30$, $d = 0.08$). All four levels of peripheral blur/opacity resulted in saccadic amplitudes that were smaller than those used with clear vision (ps < .041, ds > 0.19). The skilled players used shorter saccades than the less-skilled players (main effect of skill, $F(1, 36) = 4.24$, $p = .047$, $\eta_p^2 = .11$; no skill × blur interaction, $F(2.99, 107.67) = 1.18$, $p = .32$, $\eta_p^2 = .03$). In the *moving mask* trials central blur had less effect on saccadic amplitudes, though there were still changes in amplitude as a result of blur (Figure 2h; main effect of blur, $F(2.80, 100.65) = 14.81$, $p < .001$, $\eta_p^2 = .29$). The saccadic amplitude increased with moderate and high blur and with black central vision (ps < .03, ds > 0.13), with saccadic amplitude increasing from low to moderate blur and from moderate to high blur (both ps < .003, ds > 0.18). The main effect of skill did not reach significance ($F(1, 36) = 3.80$, $p = .06$, $\eta_p^2 = .10$; no skill × blur interaction, $F(2.80, 100.65) = 2.00$, $p = .12$, $\eta_p^2 = .05$).

Fixation time to areas of interest. The majority of the viewing time during the *moving window* trials (Figure 3a) was spent viewing, in order of priority, the ball-carrier, the defender of the ball-carrier, plus the closest attacking teammate and his defender (main effect for area of interest, $F(1.76, 63.27) = 97.08$, $p < .001$, $\eta_p^2 = .73$). As the level of blur increased, participants were more likely to view the ball-carrier, and less likely to view the defender of the ball-carrier (blur × area of interest interaction, $F(12.47, 448.79) = 4.61$, $p < .001$, $\eta_p^2 = .11$), most probably highlighting the primacy of the ball-carrier for information extraction. The level of peripheral blur also influenced the amount of time spent viewing *any* of the ten areas of interest (as opposed to other less-relevant features on the screen, main effect of blur, $F(2.97, 106.97) = 18.1$, $p < .001$, $\eta_p^2 = .34$), with participants less likely to view one of the ten areas of interest in the high blur and black opaque conditions (ps < .001, ds > 0.68). In addition, a significant skill × blur interaction ($F(2.97, 106.97) = 3.45$, $p = .02$, $\eta_p^2 = .09$) highlighted that the skilled group were more likely to view one of the ten areas of interest in the full vision and low blur conditions, but that this difference dissipated with higher levels of blur.

INSERT FIGURE 3 ABOUT HERE

The fixation priorities with central blur in the *moving mask* trials (Fig. 3b) were similar to those seen with peripheral blur (viz., the ball-carrier and his defender, and the closest attacker and his defender; main effect for area of interest, $F(1.80, 64.69) = 86.40$, $p < .001$, $\eta_p^2 = .71$). Mild and moderate central blur *increased* the time that participants spent directing their gaze towards the ten areas of interest (main effect of blur, $F(3.06, 110.22) = 4.84$, $p = .003$, $\eta_p^2 = .12$), primarily because participants increased the time they spent viewing the ball-carrier and his defender (blur × area of interest interaction, $F(12.62, 454.16) = 2.02$, $p = .02$, $\eta_p^2 = .05$). In the clear vision condition skilled players tended to spend more time than less-skilled players viewing one of the ten areas of interest; however, this expert difference dissipated with the introduction of blur (skill × blur interaction, $F(3.06, 110.22) = 3.90$, $p = .01$, $\eta_p^2 = .10$).

Discussion

The results of Experiment 1 show that when examining the performance of skilled and less-skilled basketballers on a forced-choice task, the expert advantage holds even when participants have very poor or no vision in their central or peripheral visual field. Response accuracy remained the same, and in some cases increased, despite very noticeable perturbations to vision. However, even the mildest levels of central or peripheral blur resulted in significant changes in gaze. Low blur significantly altered gaze behaviour in both the *moving window* and *moving mask* conditions. We had particularly sought to discover a level of peripheral blur that would impair information pick-up while leaving the pattern of gaze unchanged. Instead, we found the opposite. Evidently, even minor impositions to the central or peripheral visual field resulted in changes in gaze, but not in performance.

The performance of participants across the different viewing conditions in Experiment 1 is noteworthy for a number of reasons. First, the change in task from the simple two-choice one used by Ryu et al. (2013) to the four-choice task used in this experiment has lessened the likelihood that the expert advantage noted in the Ryu et al. study could have arisen as a consequence of the selective application of a simple heuristic known by the skilled but not novice players. Second, consistent with recent studies that have shown improvements in perceptual performance when viewing blurred dynamic stimuli (see Jackson et al., 2009; Mann et al., 2010b), certain levels of blur *facilitated* performance, specifically, moderate peripheral blur for the skilled players, and low peripheral blur for the less-skilled players.

Based on the collective results of Experiment 1 we began to wonder whether, despite our best endeavours to neutralise contextual information from the response slide itself (by removing the defensive players and standardizing the appearance of the remaining attacking players), there may still have been information provided that could have assisted the performance of the participants. For example, skilled basketball players are likely to know that passing to teammates with closer proximity will lower the risk of pass interception and is a much more common pass option. By showing the proximity of the teammates to the ball-carrier in the response slide, it is possible that the decisions of skilled players were biased towards what was ultimately the more correct option. Before progressing with other studies – and making potentially erroneous conclusions based on the results of Experiment 1 – we decided to first investigate whether the response slides typically used in studies of this nature do inadvertently contain information that could be utilised by skilled but not less-skilled players to bias their responses and could explain the expert advantage found in Experiment 1.

Experiment 2

In Experiment 2 we asked skilled and less skilled basketball players to make pass selection decisions of the type performed in Experiment 1 but when they only saw the response slide and no preceding video. Three different response slides were compared – one identical to that used in Experiment 1, one in which the image of the ball-carrier was replaced by a ball (thereby removing the posture but not location of the ball-carrier), and one in which the ball-carrier was completely removed (thereby removing both location and posture information). Given the fixational priority participants show towards the ball-carrier, we sought to establish whether the position and/or posture of the ball carrier shown in the response slide aids response selection.

Method

Fifteen skilled male basketball players (*M* age = 24.9, *SD* = 3.3; *M* playing experience = 11.8 yrs, *SD* = 4.1; all were guards in their University League) and 15 less-skilled players (*M* age = 23.1, *SD* = 5.1; *M* playing experience = 2.7 yrs, *SD* = 2.3; recreational level) took part. None of the participants in Experiment 2 had participated in Experiment 1.

The final frame of each of the 8 video clips used in Experiment 1 was edited to create three different types of response slide for each clip (see Figure 4): (i) a '*posture + position*' slide identical to that used in Experiment 1; (ii) a '*position only*' slide where the ball-carrier was replaced by an image of a basketball; and (iii) a '*no ball-carrier*' slide where the ball-carrier was completely removed. A mirror-image of each of the 24 response slides was created to double the number of response slides whilst reducing the potential confound of showing previously seen images. The resulting 48 response slides were projected (SANYO PLC-XU106K) onto a large screen (image size: 2.5 × 2.3 m) and presented to participants in the same randomized order. Participants sat 3 m from the screen so that the horizontal and vertical extents of the screen subtended 47 × 43° of visual angle respectively. The task, as in Experiment 1, was to decide which of the four attacking teammates shown in the response slide was best positioned to receive a pass. Response slides were shown for 5 s, after which participants wrote their response (Player 1, 2, 3 or 4) on an answer sheet. Participants' eye movements were not recorded and there were no gaze-contingent manipulations applied. The entire test session took around 20 min.

Response accuracy (% trials correct) was the only dependent measure and was analysed using a 2 (Skill: skilled, less-skilled) × 3 (Response-slide: posture + position, position only, no ball-carrier) ANOVA with repeated measures on the second factor.

INSERT FIGURE 4 ABOUT HERE

Results and Discussion

Skilled and less-skilled participants were able to select the most appropriate player to pass to on the basis of information present in the response slides (Figure 5a). The response accuracy of the skilled players was at better-than-chance levels irrespective of the type of response slide (all *p*s < .001, *d*s > 2.28), whereas less-skilled players performed above chance levels only when viewing the *posture + position* and *position only* response slides (both *p*s < .019, *d*s > 1.42; skill × response slide interaction, $F(2, 56) = 3.71$, $p = .03$, $\eta_p^2 = .12$). The skilled players responded more accurately than their less-skilled counterparts irrespective of the response slide (main effect for skill, $F(1, 28) = 51.94$, $p < .001$, $\eta_p^2 = .65$). Response accuracy was lower for the *no ball-carrier* response slide than it was for both the *posture + position* and *position only* response slides (both *p*s < .001, *d*s > 1.05; main effect for response slide, $F(2, 56) = 42.04$, $p < .001$, $\eta_p^2 = .60$). There was no difference in performance on the *posture + position* and *position only* response slides ($p = .37$, $d = 0.10$).

INSERT FIGURE 5 ABOUT HERE

Based on our expectations prior to commencing Experiment 1, the findings of Experiment 2 were surprising to the extent that they revealed that static response slides can provide significant contextual information to support better-than-chance responses by *both* skill groups in the absence of any video information. There was a clear demonstration, consequently, that the response slides used in Experiment 1 contained sufficient information to provide a basis for response selections that were at better-than-chance levels. The similarity of performance for the *posture + position* and *position only* response slides showed that the information for better-than-chance judgements is unlikely to come from the posture of the ball-carrier. Rather, the *position only* and *no ball-carrier* comparison showed that a large proportion of the information available must come from the position of the ball-carrier, most likely relative to the position of the other players. Remarkably though, the response accuracy of the skilled players was still better-than-chance even when the location of the ball-carrier was unknown. This might be because skilled players can infer the best player to pass to based on the proximity to the basket.

The results of this experiment bring into question the conclusions from Experiment 1 that the expert advantage was due to superior information pick-up from central and peripheral vision. Rather, the findings from Experiment 2 suggest that this expert advantage might be at least partially, or perhaps entirely, due to the different amounts of information that players of different skill levels can extract from the static response slides. Importantly, the findings have wider implications for a range of studies that have examined the perceptual-cognitive attributes of expertise by employing freeze-frame presentations of the last scene from a video clip (e.g., Mann et al., 2009; Raab & Johnson, 2004, 2007).

Experiment 3

In Experiment 3, we set out to find a way of minimizing the influence of the response slide on response selection while ensuring a sufficiently robust means of registering the choice made by participants. We compared four different response options: (i) a slide that was simply the final (unedited) frame of the preceding video clip (cf. Mann et al., 2009; Raab & Johnson, 2004, 2007); (ii) the *posture + position*, and (iii) *no ball-carrier* slides from Experiment 2; and (iv) a slide simply showing a still image of a vacant basketball court. Participants selected the most appropriate player to pass to, both when the response slide was, and was not, preceded by a video clip. This was done to (1) determine the extent to which any information pick-up from the video was additional to that available solely from the response slide and (2) to ensure that the response slide could still unambiguously measure responses when observing video footage.

Method

Fifteen skilled male basketball players (*M* age = 25.2, *SD* = 3.2; *M* playing experience = 11.1 yrs, *SD* = 4.4; all playing as a guard in their University League) and 17 less-skilled players (*M* age = 22.4, *SD* = 3.8; *M* playing experience = 2.0 yrs, *SD* = 2.4) who had not participated in either of the previous experiments took part in Experiment 3.

The final frame of each of the eight video clips used in Experiment 1 was edited to create four different response slides (Figure 4): (i) a '*full-image*' slide showing an unedited copy of the final frame; (ii) a '*posture + position*' slide identical to that used in Experiment 2 (and Experiment 1); (iii) a '*no ball-carrier'* slide identical to that used in Experiment 2; and (iv) a '*vacant court*' slide showing a blank court with a ball initially positioned at the centre of the free-throw line. The position of the ball in the *vacant court* slide was controlled by a computer mouse so that participants could indicate the position on the court where they believed the player best positioned to receive the pass was standing (i.e., the position of their feet). The attacking player closest to the mouse click was taken as the participant's response based on a comparison of the distances between the screen-based x-y coordinates at the centre of the ball (when the mouse click took place) and at the centre of the feet of the four attacking teammates (mid-point of the stance). All 32 of the response slides created were mirrored to produce 64 response slides.

In half of the trials (*video-clip* condition), the corresponding 7 s video clip preceded presentation of the response slide while in the other half (*no video-clip* condition), a blank screen was shown for 7 s, followed by presentation of the response slide. Each response condition (4 response slide types × video/no video) was presented in a separate block of 8 trials and was preceded by 2 practice trials. The order of presentation of each block and each trial within a block was randomized across participants and response slides were evenly distributed across the different conditions. The video clips and response slides were projected in an identical fashion to Experiment 2. Participants selected the player that they felt was best placed to receive the ball by responding with a button press on a game pad or, for the vacant court responses, a mouse click.

Response accuracy scores were submitted to a 2 (Skill: skilled, less-skilled) × 2 (Video: *video-clip, no video-clip*) × 4 (Response-slide: *full-image, posture + position, no ball-carrier, vacant court*) ANOVA with repeated measure on the latter two factors.

Results and Discussion

The only slide that did not provide information to facilitate better-than-chance responses was the vacant court slide (Figure 5b). The crucial video × response slide interaction (F(3, 90) = 14.88, p < .001, η_p^2 = .33) showed that response accuracies did not differ between the different slides when preceded by the video (F(3, 90) < 1), but there were clear differences in accuracy when the video was not shown (F(3, 90) = 18.03, p < .001, η_p^2 = .38). Only with the vacant-court slide was the response accuracy of both groups no better than chance (ps > .69, ds < 0.21).

Consistent with Experiment 2, the response slide which provided vision of the ball-carrier (*posture + position*) contained sufficient information to permit both skill groups to make better-than-chance responses regardless of whether or not the response slide was preceded by a video. Surprisingly, performance did not differ when viewing the *full-image* slide, suggesting that it is the position of the ball-carrier (relative to their team-mates) rather than information from the other players (attacking or defensive) that is most pivotal to success. Apparently the relative positions of the defenders and the posture of the attacking teammates provides no additional information to assist performance in this task.

The critical finding from Experiment 3 though was the discovery of a response slide, the *vacant court*, from which neither group was able to extract information to permit better-than-chance selections. Further, this same response condition when preceded by a video produced significantly higher response accuracy – and accuracies no different to those achievable using the other response slides – strongly suggesting that it is possible to reliably engender responses from participants without providing supplementary information.

Experiment 4

Experiment 4 had three major objectives. The first was to replicate Experiment 1 but on this occasion by using the mouse click response on a blank court. Second, because the results of

Experiment 1 suggested that information pick-up could be sustained despite surprisingly high levels of peripheral and central blur, in Experiment 4 we also sought to establish the level of blur that influenced information pick-up in each of the central and peripheral fields of vision alone. To do so we extended the ensemble of viewing conditions by adding conditions that combined blur in one sector of the visual field with black opacity in the other. Third, because particular levels of blur *facilitated* performance in Experiment 1, in Experiment 4 we added uniform levels of blur across the whole (central + peripheral) visual field to establish whether any facilitatory effect was a result of uniform blur, or an effect of blur in one sector relative to the other.

Method

Participants

Eighteen skilled male basketball players (*M* age = 24.9, *SD* = 2.9; *M* playing experience = 13.4 yrs, *SD* = 4.1; playing as a guard in the top tier of their University League) and 18 less-skilled players (*M* age = 22.2 *SD* = 2.6; *M* playing experience = 1.8 yrs, *SD* = 1.1) volunteered for Experiment 4, none of whom had participated in any of the previous experiments.

Apparatus, Test Materials, and Procedure

The set-up and procedures were identical to Experiment 1 with two key exceptions. First, a mouse click on the *vacant court* slide was used to register responses. Second, an additional ten viewing conditions were used to create those combinations of conditions seen in Figure 6 in which the central and/or the peripheral sectors of the visual field contained (i) clear vision, (ii) low blur, (iii), moderate blur, (iv) high blur, or (v) was fully opaque. Combinations a-i shown in Figure 6 replicate those used in Experiment 1 while the remainder of the conditions were new. The same eight video-clips used in Experiment 1 were viewed in each of the 19 viewing conditions. The test consisted of a total of 152 trials (8 trials × 19 viewing conditions), with testing divided into four blocks of 38 trials. Participants completed two blocks in each of two 60-min testing sessions on separate days. The order of the blocks was counterbalanced across participants and the trials in each block were randomised.

INSERT FIGURE 6 ABOUT HERE

Dependent Variables and Data Analysis

Similar to Experiment 1, the dependent variables collected for analysis were *response accuracy*, *response time, mean fixation duration, mean saccadic amplitude,* and *percentage of total viewing time* spent viewing each of the ten areas of interest. For the first four dependent variables, data analysis comprised of five discrete sets of 2 (Skill) × 5 (Blur) ANOVAs with repeated measures on the second factor. The five discrete ANOVAs were used for each of the five rows shown in Figure 6. Planned *t*-tests determined differences from the full vision condition, progressive differences between blur levels, and compared response accuracy levels to chance/guessing. In addition to the two-way ANOVAs, 3-way 2 (Skill) × 5 (Blur) × 10 (Area of interest) ANOVAs with repeated measures on the last two factors were conducted on the *percentage of total viewing time*. The response accuracy and response time data were also subjected to a 2 (Skill) × 19 (Clip exposure: 1^{st}, 2^{nd}, 3^{rd} …, 19^{th} presentation) ANOVA with repeated measures on the second factor to check whether there were any effects of learning as a result of repeated exposure to the individual clips.[4]

Results and Discussion

Replicating Experiment 1: moving window (clear/blur) and moving mask (blur/clear)

Response accuracy and response time. Despite changing the response slide, the response accuracies in Experiments 1 and 4 were remarkably similar. In the *moving window*

[4] There were no changes in response accuracy or response time as a consequence of repeated exposure to the video clips. For both measures there was no main effect for clip and no skill × clip exposure interaction (all *F*s < 1).

(clear/blur) trials (Figure 7a) the skilled players were more accurate than the less-skilled players irrespective of the level of peripheral blur (main effect of skill, $F(1, 34) = 95.96$, $p < .001$, $\eta_p^2 = .74$; no skill × blur interaction, $F(4, 136) = 1.63$, $p = .17$, $\eta_p^2 = .05$; no main effect for blur, $F(4, 136) = 1.89$, $p = .12$, $\eta_p^2 = .05$). Similarly in the *moving mask (blur/clear)* trials (Figure 7b), the response accuracy of the skilled players was higher irrespective of the level of central blur (main effect of skill, $F(1, 34) = 146.94$, $p < .001$, $\eta_p^2 = .81$; no skill × blur interaction, $F(4, 136) < 1$; no main effect for blur, $F(4, 136) < 1$). In all the *moving window (clear/blur)* and *moving mask (blur/clear)* conditions the response accuracy of the skilled players was above chance levels (all *p*s < .001, *d*s > 6.32), whereas for the less-skilled players this was only true when central vision was clear (*p*s < .035, *d*s > 0.56) and never when central vision was in any way impaired. When compared to the clear condition, the accuracy of the less-skilled players *increased* with moderate ($p = .043$, $d = 0.67$) and high ($p = .048$, $d = 0.53$) peripheral blur but not with low blur ($p = .83$, $d = 0.05$) or with opaque occlusion ($p = .07$, $d = 0.72$). The skilled players did not increase their accuracy in any of the blur conditions.

INSERT FIGURE 7 ABOUT HERE

Response times were influenced by the level of peripheral blur in the *moving window (clear/blur)* trials (Figure 7c; main effect of blur, $F(2.90, 98.57) = 7.44$, $p < .001$, $\eta_p^2 = .18$), with response times increasing with high peripheral blur ($p = .013$, $d = 0.34$) and black peripheral vision ($p < .001$, $d = 0.54$). Response times were not influenced by the skill level of the participants (no main effect of skill, $F(1, 34) < 1$; no skill × blur interaction, $F(2.90, 98.57) < 1$). Central blur also influenced response times in the *moving mask (blur/clear)* trials (Figure 7d; main effect of blur, $F(3.25, 110.62) = 3.29$, $p = .02$, $\eta_p^2 = .09$), with moderate central blur ($p = .03$, $d = 0.34$) and black central vision ($p = .01$, $d = 0.33$) resulting in longer response times.

Again, response times were not influenced by the skill of the participants (no effect of skill, $F(1, 34) < 1$; no skill × blur interaction, $F(3.25, 110.62) < 1$). When compared to Experiment 1, response times were less influenced by blur in Experiment 4, most likely because participants took more time to process the information in the slides in Experiment 1.

Fixation durations. The fixation durations were altered by peripheral blur in the *moving window (clear/blur)* trials (Figure 7e; main effect of blur, $F(2.50, 85.07) = 14.17$, $p < .001$, $\eta_p^2 = .29$), with the durations increasing with low and moderate peripheral blur (ps < .003, ds > 0.50) and decreasing with black peripheral vision ($p = .005$, $d = 0.71$). Fixation durations were not influenced by the skill level of participants ($F(1, 34) < 1$; no skill × blur interaction, $F(2.50, 85.07) < 1$). Mild, moderate and high *central* blur significantly lengthened the fixations in the *moving mask (blur/clear)* trials (Figure 7f; ps < .001, ds > 0.89; main effect of blur, $F(2.61, 88.68) = 22.81$, $p < .001$, $\eta_p^2 = .40$). However, with central blur the skilled participants used longer fixations than the less-skilled participants did (main effect for skill, $F(1, 34) = 4.25$, $p = .047$, $\eta_p^2 = .11$; no skill × blur interaction, $F(2.61, 88.68) = 1.88$, $p = .15$, $\eta_p^2 = .05$).

Saccadic amplitude. Saccadic amplitudes were somewhat resistant to peripheral blur, with the key reduction occurring with black peripheral vision (Figure 7g; main effect of blur, $F(3.06, 103.94) = 81.08$, $p < .001$, $\eta_p^2 = .71$). Skill significantly interacted with blur ($F(3.06, 103.94) = 3.48$, $p = .02$, $\eta_p^2 = .09$; no main effect for skill, $F(1, 34) < 1$), primarily because the skilled players decreased their saccadic amplitude from high blur to black peripheral vision ($p < .001$, $d = 1.58$) while the less-skilled players did so from low to moderate peripheral blur ($p = .008$, $d = 0.23$) and from high blur to black periphery ($p < .001$, $d = 1.55$). With central blur in the *moving mask (blur/clear)* trials, longer saccades were found with high central blur and black central vision (Figure 7h; ps < .001, ds > 0.51; main effect of blur, $F(4, 136) = 19.14$, $p < .001$,

$\eta_p^2 = .36$). In this case the relationship was not mediated by the skill level of the participants (no main effect of skill, $F(1, 34) = 1.30$, $p = .26$, $\eta_p^2 = .04$; no skill × blur interaction, $F(4, 136) < 1$).

Fixation time to areas of interest. Similar to Experiment 1, in the *moving window (clear/blur)* trials participants spent most of their time viewing the ball-carrier, the defender of the ball-carrier, and the closest attacker and defender (Figure 8a; main effect of area of interest, $F(1.60, 54.26) = 105.71$, $p < .001$, $\eta_p^2 = .76$). The time allocated to the different areas of interest remained similar for all of the blur conditions *except* with the black periphery (area of interest × blur interaction, $F(9.43, 320.49) = 3.48$, $p < .001$, $\eta_p^2 = .09$) when less time was spent viewing the defender of the ball-carrier ($p = .042$, $d = 0.53$) and the closest attacker + defender (ps < .001, ds > 0.71). When compared to the clear condition, participants were less likely to look towards any of the ten areas of interest with the black periphery ($p < .001$, $d = 0.99$; main effect of blur, $F(4, 136) = 15.31$, $p < .001$, $\eta_p^2 = .31$). Skilled participants spent more time than the less-skilled participants looking at the ten areas of interest in the full clear, low and moderate peripheral blur conditions (ps < .05, ds > 0.51), but not in the other two conditions (ps > .58, ds < 0.19; skill × blur interaction, $F(4, 136) = 3.49$, $p = .009$, $\eta_p^2 = .09$). All other effects were non-significant. The fixational priorities in the *moving mask (blur/clear)* conditions (Figure 8b) were essentially identical to those found in the *moving window (clear/blur)* trials, despite central vision being blurred or even opaque (main effect for area of interest, $F(1.74, 59.04) = 95.73$, $p < .001$, $\eta_p^2 = .74$). When compared to the clear condition, the time spent viewing the ten areas of interest tended to be reduced more with black central vision ($p = .10$, $d = 0.32$) than for any other blur condition (ps > .32, ds < 0.18; main effect of blur, $F(2.45, 83.40) = 3.00$, $p = .045$, $\eta_p^2 = .08$). Across all conditions the skilled players spent more time than the less-skilled players directing their central vision towards the ten areas of interest even though this area of the visual field was blurred or opaque (main effect for skill, $F(1, 34) = 7.56$, $p = .009$, $\eta_p^2 = .18$).

INSERT FIGURE 8 ABOUT HERE

In summary, the expert advantage for response accuracy was preserved across all the *moving window* and *mask* conditions in Experiment 4, just as it had been in Experiment 1. The skilled players showed above-chance accuracy in all viewing conditions, whereas the less-skilled players only did so when central vision was clear. The skilled players were apparently not affected by black central or peripheral vision, meaning that they could pick up information from the other clear sector of the visual field without decreasing their performance. Interestingly, we also found that the less-skilled players *increased* their performance with moderate and high peripheral blur [in Experiment 1, improvements were seen for the skilled participants with moderate peripheral blur and in the less-skilled with low peripheral blur].

The gaze behaviour across Experiments 1 and 4 was also very similar, and crucially again shows that even the lowest level of blur can result in significant changes to gaze while leaving performance unchanged. Mild central *or* peripheral blur produced immediate increases in the duration of fixations (Figure 7e & 7f; see also Bertera & Rayner, 2000; Cornelissen et al., 2005; Loschky & McConkie, 2000, 2002; Nuthmann, 2014), though higher levels of blur were required to alter the saccadic amplitude: the amplitude decreased with moderate peripheral blur for the less-skilled participants, and only with black peripheral vision for the skilled players (consistent with the usual finding that a window decreases saccadic amplitude, see Bertera & Rayner, 2000; Cornelissen et al., 2005; Loschky & McConkie, 2000, 2002; Nuthmann, 2014). On the other hand, high central blur and black central vision both increased the amplitudes for all participants (see Cornelissen et al., 2005; Miellet et al., 2010; Nuthmann, 2014).

Information pick-up from each sector of the visual field in isolation: moving window

(blur/opaque) and moving mask (opaque/blur) conditions

Response accuracy and response time. When viewing with central vision only in the *moving window (blur/opaque)* trials (Figure 9a), the response accuracy of the skilled players was better than it was for the less-skilled players with clear, low and moderate central blur (ps < .001, ds > 1.90), but not with high blur (p = .21, d = 0.43) or when the screen was completely black (p = .27, d = 0.37; skill × blur interaction, F(4, 136) = 15.26, p < .001, η_p^2 = .31; main effect for skill, F(1, 34) = 40.00, p < .001, η_p^2 = .54; main effect of blur, F(4, 136) = 30.29, p < .001, η_p^2 = .47). When compared to the clear central vision condition, skilled players responded less accurately with moderate and high central blur and with fully black vision (ps < .001, ds > 0.88). The response accuracy of the skilled players decreased from low to moderate blur (p = .011, d = 0.76) and from moderate to high central blur (p < .001, d = 2.37). The accuracy of the less-skilled players was only better-than-chance when central vision was clear (p < .001, d = 2.83).

When viewing with only peripheral vision in the *moving mask (opaque/blur)* trials (Figure 9b), the skilled players responded more accurately than the less skilled players in *all* blur conditions (ps < .001, ds > 1.45) except, unsurprisingly, when vision was completely black (p = .27, d = 0.37; skill × blur interaction, F(4, 136) = 10.06, p < .001, η_p^2 = .23; main effect of skill, F(1, 34) = 47.50, p < .001, η_p^2 = .58; main effect of blur, F(4, 136) = 12.98, p < .001, η_p^2 = .28). Remarkably, the skilled players performed at better-than-chance levels even when viewing with only high peripheral blur and no central vision. Compared to the clear peripheral condition, skilled players' response accuracy decreased with moderate and high peripheral blur, and with no vision (ps < .044, ds > 0.53), but not with low blur (p = .28, d = 0.38). The response accuracy of the skilled players decreased only from high peripheral blur to full occlusion (p < .001, d = 1.71).

INSERT FIGURE 9 ABOUT HERE

When compared to clear vision, the response times in the *moving window (blur/opaque)* trials were slower with every level of blur (Figure 9c; *p*s < .001, *d*s > 0.43) except with fully opaque vision ($p = .89$, $d = 0.02$; main effect of blur, $F(2.98, 101.25) = 7.62$, $p < .001$, $\eta_p^2 = .18$; no main effect for skill, $F(1, 34) < 1$, no skill × blur interaction, $F(2.98, 101.25) < 1$). In contrast, response times did not differ to any great extent in the *moving mask (opaque/blur)* trials (Figure 9d). There was a significant main effect of blur ($F(2.77, 94.30) = 3.27$, $p = .03$, $\eta_p^2 = .09$; no main effect of skill, $F(1, 34) < 1$; no skill × blur interaction, $F(2.77, 94.30) = 1.39$, $p = .25$, $\eta_p^2 = .04$) as response times slowed from low to moderate peripheral blur ($p = .005$, $d = 0.29$).

Fixation durations. In the *moving window (blur/opaque)* trials (Figure 9e) fixations became longer when low central blur was introduced ($p < .001$, $d = 0.82$) but then stabilised (main effect of blur, $F(1.40, 47.72) = 4.89$, $p = .021$, $\eta_p^2 = .13$; no main effect of skill, $F(1, 34) = 2.02$, $p = .16$, $\eta_p^2 = .06$; no blur × skill interaction, $F(1.40, 47.72) < 1$). The same outcome was found in the *moving mask (opaque/blur)* trials (Figure 9f) with the duration increasing from clear to low peripheral blur ($p < .001$, $d = 0.36$) and then stabilising (main effect of blur, $F(1.35, 45.77) = 4.01$, $p = .04$, $\eta_p^2 = .11$; no main effect of skill, $F(1, 34) = 1.90$, $p = .18$, $\eta_p^2 = .05$; no blur × skill interaction, $F(1.35, 45.77) = 1.59$, $p = .22$, $\eta_p^2 = .05$).[5]

Saccadic amplitude. In the *moving window (blur/opaque)* trials the size of the saccades increased with progressive increases in central blur (Figure 9g; main effect of blur, $F(1.38, 46.92) = 34.35$, $p < .001$, $\eta_p^2 = .50$; no main effect of skill, $F(1, 34) = .002$, $p = .97$, $\eta_p^2 < .001$; no skill × blur interaction, $F(1.38, 46.92) = .44$, $p = .57$, $\eta_p^2 = .01$.), with significant changes across all successive comparisons (*p*s < .038, *d*s > 0.21) except between low and moderate

[5] The effect of blur was still present in both the moving window (blur/opaque) and moving mask (opaque/blur) conditions when the fully opaque condition was removed from the analysis (*p*s < .001).

central blur (p = .16, d = 0.15). In the *moving mask (opaque/blur)* trials the saccades also lengthened with increases in blur (Figure 9h; main effect of blur, $F(1.60, 54.51) = 8.98$, $p < .001$, $\eta_p^2 = .21$; no main effect of skill, $F(1, 34) < 1$; no skill × blur interaction, $F(1.60, 54.51) < 1$) with the saccadic amplitude increasing from moderate to high peripheral blur (p = .001, d = 0.33) and decreasing from high blur to full opacity (p < .001, d = 0.77).[6]

Fixation time to areas of interest. Participants allocated their fixations towards the usually prioritised areas in the *moving window (blur/opaque)* trials *except* when viewing with high central blur and fully opaque vision (Figure 10a; blur × area of interest interaction, $F(9.15, 310.99) = 28.65$, $p < .001$, $\eta_p^2 = .46$; main effect of blur, $F(4, 136) = 150.27$, $p < .001$, $\eta_p^2 = .82$; main effect of area of interest, $F(2.25, 76.61) = 63.88$, $p < .001$, $\eta_p^2 = .65$). In those cases, central gaze was directed in a random fashion with approximately equal time allocation towards all ten areas of interest. Essentially, the gaze behaviour with high central blur was akin to that with completely opaque vision (i.e., it was randomly distributed). With peripheral blur in the *moving mask (opaque/blur)* trials (Figure 10b), the time spent viewing the areas of interest only changed in the fully opaque condition (p < .001, d = 1.32), suggesting that the necessary information to guide gaze was present with every level of peripheral blur (blur × area of interest interaction, $F(12.35, 419.81) = 22.79$, $p < .001$, $\eta_p^2 = .40$; main effect of blur, $F(2.14, 72.73) = 132.21$, $p < .001$, $\eta_p^2 = .80$; main effect of area of interest, $F(2.59, 88.11) = 78.08$, $p < .001$, $\eta_p^2 = .70$).

INSERT FIGURE 10 ABOUT HERE

Here we have individually isolated central and peripheral vision so that, unlike in the previous comparisons, there was not the opportunity for participants to compensate for blur in

[6] The effect of blur was still present in both the moving window (blur/opaque) and moving mask (opaque/blur) conditions when the fully opaque condition was removed from the analysis (ps < .001).

one part of the visual field by information pick-up from the other sector. Evidently, task performance continues to be very good despite considerable blur in the central or peripheral visual field alone. The response accuracy of the skilled players was compromised by moderate central or peripheral blur, but high central blur was necessary to completely impair information pick-up, and even the highest level of peripheral blur was not enough to prevent information pick-up. The response accuracy of the skilled players remained better than chance under all circumstances *except* where there was high central blur (with a black periphery) or, unsurprisingly, when there was no visual information at all. Sufficient information was extracted with high peripheral blur (and black central vision) to perform at better-than-chance levels, but not with high central blur, demonstrating the greater susceptibility of central vision to blur.

The analysis of the gaze data again highlights how susceptible gaze behaviour can be to even mild levels of blur. Low central blur increased the duration of the fixations and increased the size of the saccades, while low peripheral blur also increased the duration of the fixations. The analysis of the fixational priorities provides a very good proxy measurement for the response accuracy of the skilled participants. More specifically, only in those conditions where the response accuracy of the skilled performers was reduced to chance-guessing (high central blur and full opaque vision) was there a measurable change in the areas of interest fixated by participants. In the conditions where there was a relative, but not total decrease in performance (viz., moderate central blur and high peripheral blur), the gaze allocation of participants tended to be indistinguishable from that relied on with full vision. This provides some indication that, with those levels of blur, skilled participants still look towards the same areas that they would usually do, but that the blur has somewhat impaired their ability to pick-up the information necessary to support optimal performance in this task.

The effect of uniform blur: central + peripheral blur

Response accuracy and response time. The skilled players responded more accurately than the less skilled players at every level of full-field blur (Figure 11a; *p*s < .001, *d*s > 1.48) though, encouragingly, not when the screen was completely black (skill × blur interaction, $F(4, 136) = 15.09$, $p < .001$, $\eta_p^2 = .31$; main effect of skill, $F(1, 34) = 85.44$, $p < .001$, $\eta_p^2 = .72$; main effect of blur, $F(4, 136) = 21.95$, $p < .001$, $\eta_p^2 = .39$). Compared to when the visual field was clear, the response accuracy of the skilled players decreased only with high blur (or with black occlusion, *p*s < .001, *d*s > 1.26). Response accuracy decreased significantly from low to moderate blur ($p = .04$, $d = 0.69$) and from high blur to full opacity ($p < .001$, $d = 1.52$). Blur influenced the response times of all participants in a similar manner (Figure 11b; main effect of blur, $F(2.87, 97.50) = 6.95$, $p < .001$, $\eta_p^2 = .17$; no main effect of skill, $F(1, 34) < 1$, no skill × blur interaction, $F(2.87, 97.50) < 1$). Compared to the fully clear condition, response times were slower with moderate and high blur and with fully black/opaque vision (*p*s < .04, *d*s > 0.28).

INSERT FIGURE 11 ABOUT HERE

Fixation durations. Fixations became progressively longer with each increase in full-field blur (Figure 11c; *p*s < .001, *d*s > 0.54; main effect of blur, $F(1.59, 54.18) = 19.66$, $p < .001$, $\eta_p^2 = .37$; no main effect of skill, $F(1, 34) < 1$; no skill × blur interaction, $F(1.59, 54.18) < 1$), reversing only when the screen was completely black ($p = .003$, $d = 0.72$).

Saccadic amplitude. The size of the saccades did not change with increases in full-field blur (Figure 11d; no main effect of blur, $F(1.45, 49.30) = 2.37$, $p = .12$, $\eta_p^2 = .07$; no main effect of skill, $F(1, 34) < 1$; no blur × skill interaction, $F(1.45, 49.30) < 1$).

Fixation time to areas of interest. The fixational priorities of the participants remained similar with low, moderate, and high full-field blur and only changed in the fully opaque condition when gaze was randomly allocated across all ten areas of interest (main effect of area of interest, $F(2.31, 78.43) = 121.22$, $p < .001$, $\eta_p^2 = .78$). More time was spent viewing the ten areas of interest with moderate and high blur than in the normal fully clear condition (ps < .043, ds > 0.37; blur × area of interest interaction, $F(12.53, 425.90) = 25.37$, $p < .001$, $\eta_p^2 = .43$; main effect of blur, $F(2.79, 94.87) = 269.50$, $p < .001$, $\eta_p^2 = .89$).

Uniform blur across the whole visual field produced results that essentially mirrored those seen with central blur and a black periphery (Figure 9a). Moderate blur impaired performance, though not enough to completely impair information pick-up. In contrast to the earlier findings in Experiments 1 and 4, no improvements in performance were evident for any level of full-field blur. This suggests that any facilitatory effect of blur is likely to be a result of greater blur in one sector of the visual field *relative to* the other.

Low full-field blur resulted in an immediate increase in the duration of the fixations without changing the *breadth* of the search (i.e., the mean saccadic amplitude). This suggests that it is the manipulation of peripheral vision *relative to* central vision (or vice versa) that changes the breadth of the visual search (i.e., the mean saccadic amplitude), rather than it being a simple by-product of the presence of blur. The important implication for gaze-contingent studies is that even mild blur in one (but not the other) sector of the visual field is likely to produce changes in the breadth of the visual search (see also Loschky & McConkie, 2002). Crucially though, and in agreement with the results seen for the *moving window (blur/opaque)* and *moving mask (opaque/blur)* conditions (Figure 10), only when response accuracy was reduced to chance levels (in the fully opaque condition) was there a commensurate change in the fixational priorities of the skilled participants. Gaze priorities were largely unchanged with low, moderate and high blur, suggesting that any relative reduction in response accuracy was a result of impaired information pick-up rather than an inability to direct gaze towards the areas of interest.

General Discussion

The purpose of the series of experiments reported in this paper was to examine the relative contributions of central and peripheral vision to response selection in dynamic viewing conditions. The evidence accumulated across the four experiments provides new insights into a number of questions surrounding the role that different sectors of the visual field play in expertise in dynamic, time-constrained tasks.

The locus of the expert advantage

It is well-established that experts exhibit superior performance on domain-specific tests of response selection (e.g., Allard, Graham, & Paarsalu, 1980; Horswill & McKenna, 2004; Starkes, 1987; Underwood et al., 2008), and as a result, it is commonly assumed that this expert advantage stems, at least in part, from the experts' superior use of peripheral vision. However, until recently, there has been very little empirical evidence to demonstrate such a difference. Ryu et al. (2013) employed a gaze contingent display to show that expert basketball players maintained their superior response selection when compared to less skilled controls even when information was only available to central or peripheral vision. Experiment 4 confirmed this conclusion. For central vision, when viewing with the *moving window (clear/blur)* in Experiments 1 and 4, experts consistently recorded higher response accuracies than novices and performed above chance in all conditions whereas the less-skilled performers achieved only occasionally better-than-chance performance (Figures 2a & 7a). When there was no peripheral information available and central vision was blurred (*moving window (blur/opaque)*; Figure 9a) the expert advantage, and their better-than-chance responses, persisted until their central vision was either highly blurred or was completely black. The expert advantage is a strong and systematic one that holds persistently when information pick-up is possible via central vision.

When clear *peripheral* information was available and central vision was either blurred or opaque (*moving mask (blur/clear)* conditions), a persistent expert advantage was observed that held across all conditions (Figures 2b & 7b). When no central vision was available and the periphery was blurred (*moving mask (opaque/blur)* conditions) the expert advantage and their better-than-chance performance persisted for all levels of blur, disappearing only when the display was completely black. The better-than-chance responses when the only information available was a highly blurred peripheral image (and no central information) is extraordinary and highlights the robust capacity of the experts to extract salient information from even highly impoverished displays.

The influence of blur

How does blur affect information pick-up? The impact of blur on performance is largely dependent upon whether or not the whole of the visual field is blurred. When either central or peripheral vision was clear and blur was applied to the other sector, blur had relatively little impact on response accuracy or on the conclusions reached regarding the locus of expertise. However, when only central or peripheral vision was available and blur was applied to those sectors of the visual field, blur much more systematically degraded response accuracy. When low and moderate blur were applied uniformly across the *full* visual field, the responses of both the skilled and less-skilled participants closely resembled, with one exception, those seen when viewing with only central vision. Collectively this suggests that participants were almost always relying on information from central vision to perform the task. The one important exception though was seen for the skilled participants with *high* full-field blur; rather than resembling the chance-level guessing seen when viewing with central vision only, the results more closely replicated those seen when viewing with only *peripheral* vision (Figure 9b). This suggests that the skilled players had the capacity to alter their attentional focus to rely on peripheral visual information when the central vision no longer supported task performance.

Can blur facilitate performance? A number of previous studies have suggested that modest levels of blur may facilitate the performance of some perceptual tasks (e.g., Jackson et al., 2009; Mann et al., 2010b). Here we have also observed specific situations where blur improved task performance. With clear central and blurred peripheral vision, in both Experiment 1 (Figure 2a) and Experiment 4 (Figure 7a) we found conditions where peripheral blur increased response accuracy when compared to the clear control condition. For Experiment 1 this was the case for the less skilled group with low peripheral blur and for the highly skilled group with moderate peripheral blur; in Experiment 4 this was only the case for the less skilled group with moderate and high blur. No facilitatory effects were evident for the *moving mask* conditions or when blur was applied to the full visual field. These findings suggest that any improvements that accrue are likely to occur when the periphery is more blurred than is central vision. The failure to replicate the improvement in performance seen for the skilled participants in Experiment 1 – most likely because of the more appropriate response slide adopted in Experiment 4 – suggests that any facilitatory effect might be isolated to less-skilled rather than skilled participants. The mechanism of the improvement may be related to the attenuation of concurrent peripheral demands and distractions, permitting an increased attentional focus towards critical centrally-fixated cues. Blur shifts visual attention towards the clear regions of the visual field (Enns & MacDonald, 2013; Loschky & McConkie, 2002; Nuthmann, 2014) and it is possible that in our study peripheral blur encouraged the less-skilled participants to attend towards the more salient (and evidently important) information located in their central vision.

Even mild blur alters gaze. Peripheral vision can be used for direct information pick-up as well as to locate a suitable location for subsequent visual fixations. We sought to establish which of these two key roles would be influenced by a lower level of blur, and found there to be a clear and unambiguous answer. Even the lowest levels of central and peripheral blur led to considerable changes in gaze behaviour without changing performance on the task. This supports the idea that there is degeneracy in gaze patterns, that is, the pattern of visual gaze can change without necessarily altering task performance. This reinforces the view that the limiting factor to perceptual performance is possession of the requisite knowledge to use information rather than the specific pattern of gaze used during the task (Abernethy & Russell, 1987).

Blur in the majority of cases resulted in fixation durations that were longer than normal irrespective of the level of blur and where it was applied in the visual field (see Figures 2f, 7e,f, 9e,f & 11c; see also Loschky & McConkie, 2002; Nuthmann, 2014). Further, saccadic amplitudes generally decreased with peripheral blur (with the exception of low blur in Experiment 4, see Figures 2g & 7g; see also Bertera & Rayner, 2000; Cornelissen et al., 2005; Loschky & McConkie, 2000, 2002; Nuthmann, 2014) and increased with central blur (Figures 2h, 7h, 9h, & 11d; see also Cornelissen et al., 2005; Miellet et al., 2010; Nuthmann, 2014). Despite these measurable changes in gaze, participants did not necessarily alter *where* they directed their gaze (as measured by fixation time to areas of interest). As blur was introduced, participants looked towards the same key features in the display even though they changed the way that they did so. This leads to the conclusion that top-down knowledge (expertise in this study) can override much of the attentional biasing found when blur influences gaze (Enns & MacDonald, 2013; Loschky et al., 2014; Nuthmann, 2014).

The selection of the next gaze location appears to be more important than peripheral information pick-up when the eyes move throughout a scene. Motter and Simoni (2008) have shown that information extraction from peripheral vision is good when the eyes are stationary, but may be limited when the eyes are freely able to move. In their task participants identified the presence of a stationary target object either when they (i) *had* to, (ii) *were allowed* to, or (iii) *were forbidden* to move their eyes. When the eyes were *not* allowed to move, targets could be found further from the fovea than when the eyes did move. Yet, when allowed to move their eyes participants did so as it proved to be quicker for finding targets than it was when simply relying on peripheral information pick-up to locate the target. As a result, when the eyes are freely able to move, the key role of peripheral vision may be to locate the next target for the relocation of central vision. This is consistent with our finding that gaze is more sensitive to blur than is information pick-up, though our results also show that peripheral information pick-up is still useful when the eyes move. When using only peripheral vision in the *moving mask (opaque/blur)* trials, skilled participants continued to direct their gaze towards the usual areas of interest, yet still extracted sufficient information from their periphery to sustain their usual level of accuracy.

This lead us to the question of what might be the most suitable level of blur to use when applying gaze-contingent displays to dynamic tasks. In this study we found that the time spent viewing the ten areas of interest provided a good proxy measurement for performance, i.e., performance decreased to chance levels when the participants were no longer able to direct gaze towards their typically prioritised areas of interest. Perhaps, rather than seeking a level of blur that leaves all measures of gaze unchanged, a more realistic aim may be to find the highest level of blur that allows participants to maintain fixation towards their key areas of interest. In this experiment this was possible with moderate central blur and high peripheral blur (in conjunction with an opaque complimentary field; Figures 9 & 10). These blur levels decreased information pick-up while allowing participants to view the display features they would normally rely on.

The validity of gaze measurement for assessing attentional priorities

The vast majority of existing studies examining the gaze behaviour of experts and non-experts engaging in dynamic perceptual tasks do so without gaze-contingent manipulations and as a result use measures of gaze behaviour to infer differences in attentional priority (e.g., Bard & Fleury, 1981). The difficulty with this approach is the potential for gaze and attention to disassociate such that, if attention is directed to the periphery, the line of gaze may provide a false indication of the allocation of attention. The important question that is central to the validity of inferences drawn from usual studies of visual search is whether the allocation of gaze under normal search conditions is comparable to gaze allocation in the *moving window (clear/opaque)* trials when gaze and attention are effectively moved into alignment. The comparison of the percentage time spent viewing the areas of interest (Figures 3 & 8) reveals a highly consistent set of fixational priorities when there is clear central and peripheral vision and when central vision is clear but the periphery is black. Importantly, the conclusion that would be reached from usual gaze studies using fully clear vision would also be the conclusion reached when there is no peripheral vision. This would suggest that the potential for attention to be distributed away from the line of gaze may therefore be of less concern in gaze studies than has previously been suggested (e.g., Abernethy, 1988). Conversely, the attentional priorities did not seem to alter in any great way when central vision was black and peripheral vision was clear in the *moving mask (opaque/clear)* trials. Even though central information pick-up was not possible, gaze was still directed towards the same areas of interest. This shows that experts possess flexibility in their information pick-up and that they can, when necessary, use their peripheral vision to compensate for the loss or impairment of central information.

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Figure captions

Figure 1. Screenshots of nine different viewing conditions (a) full clear; (b-e) *moving window (clear/blur)* conditions (low, moderate, high, and opaque, respectively); (f)-(i) *moving mask (blur/clear)* conditions (low, moderate, high, and opaque, respectively) and an example of the response slide used in Experiment 1 (j).

Figure 2. Mean (a + b) response accuracy, (c + d) response time, (e + f) fixation duration, and (g + h) saccadic amplitude for the *moving window (clear/blur)* conditions (left) and *moving mask (blur/clear)* conditions (right) for skilled and less-skilled players in Experiment 1. Horizontal line (a & b) indicates the 25 % level achievable by chance/guessing; Asterisks indicate data values significantly different from the 25% level that would be achievable by chance/guessing (**$p < 0.01$, *$p < 0.05$). Error bars indicate the standard error of the mean.

Figure 3. Percentage of total viewing time towards each of the ten areas of interest across the blur conditions for the skilled and less-skilled participants: (a) *moving window (clear/blur)* conditions; (b) *moving mask (blur/clear)* conditions. Error bars indicate the standard error of the mean. Areas of interest are the ball-carrier (AB) and their defender (DB); Teammate closest to ball-carrier (A1) and defender (D1); teammate 2nd closest to ball-carrier (A2) and defender (D2); teammate 3rd closest to ball-carrier (A3) and defender (D3); and teammate furthest from ball-carrier (A4) and defender (D4).

Figure 4. Example of response slides used in Experiment 2 and 3. The top row shows examples of the three response slides used in Experiment 2: (a) *posture + position*; (b) *position only*; (c) *no ball-carrier*. The bottom row shows examples of the four response slides used in Experiment 3: (a) *full-image*; (b) *posture + position*; (c) *no ball-carrier*; (d) *vacant court* (the ball was synchronised with the mouse cursor).

Figure 5. Mean response accuracy for (a) the three different response slides in

Experiment 2, and (b) the eight different response options in Experiment 3. Horizontal line indicates the 25 % level achievable by chance/guessing; Asterisks indicate data values significantly different from the 25% level that would be achievable by chance/guessing (**$p < 0.01$, *$p < 0.05$). Error bars indicate the standard error of the mean.

Figure 6. Screenshots of the nineteen different viewing conditions in Experiment 4: (a) full clear; (b-e) *moving window (clear/blur)* conditions (low, moderate, high, and black opaque, respectively); (f)-(i) *moving mask (blur/clear)* conditions (low, moderate, high, and black opaque, respectively); (j)-(l) *moving window (blur/opaque)* conditions (low, moderate, and high, respectively); (m)-(o) *moving mask (opaque/blur)* conditions (low, moderate, and high, respectively); (p)-(s) *central + peripheral blurred* conditions (low, moderate, high, and opaque, respectively). The information in brackets (e.g., clear/blur) refers to the respective quality of the visual information in the central and peripheral sectors of the visual field.

Figure 7. Mean (a + b) response accuracy, (c + d) response time, (e + f) fixation duration, and (g + h) saccadic amplitude for the *moving window (clear/blur)* conditions (left) and *moving mask (blur/clear)* conditions (right) for skilled and less-skilled players in Experiment 4. Horizontal line (a & b) indicates the 25 % level achievable by chance/guessing; Asterisks indicate data values significantly different from the 25% level that would be achievable by chance/guessing (**$p < 0.01$, *$p < 0.05$). Error bars indicate the standard error of the mean.

Figure 8. Percentage of total viewing time towards each of the ten areas of interest across the blur conditions for the skilled and less-skilled participants in Experiment 4: (a) *moving window (clear/blur)* conditions; (b) *moving mask (blur/clear)* conditions. Error bars indicate the standard error of the mean.

Figure 9. Mean (a + b) response accuracy, (c + d) response time, (e + f) fixation

duration, and (g + h) saccadic amplitude for the *moving window (blur/opaque)* conditions (left) and *moving mask (opaque/blur)* conditions (right) for skilled and less-skilled players in Experiment 4. Horizontal line (a & b) indicates the 25 % level achievable by chance/guessing; Asterisks indicate data values significantly different from the 25% level that would be achievable by chance/guessing (**$p < 0.01$, *$p < 0.05$). Error bars indicate the standard error of the mean.

Figure 10. Percentage of total viewing time towards each of the ten areas of interest across the blur conditions for the skilled and less-skilled players in Experiment 4: (a) *moving window (blur/opaque)* conditions; (b) *moving mask (opaque/blur)* conditions. Error bars indicate the standard error of the mean.

Figure 11. *Central + peripheral blurred* conditions in Experiment 4: (a) mean response accuracy; (b) mean response time; (c) mean fixation duration; (d) mean saccade amplitude for skilled and less-skilled players. Horizontal line (a) indicates the 25 % level achievable by chance/guessing; Asterisks signal data values significantly different from the 25% level that would be achievable by chance/guessing (**$p < 0.01$, *$p < 0.05$). Error bars indicate the standard error of the mean.

Figure 1

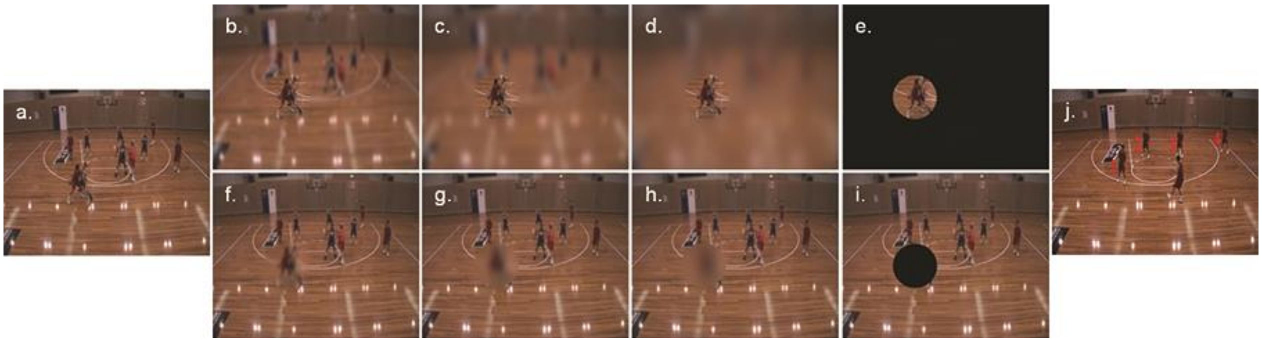


Figure 2

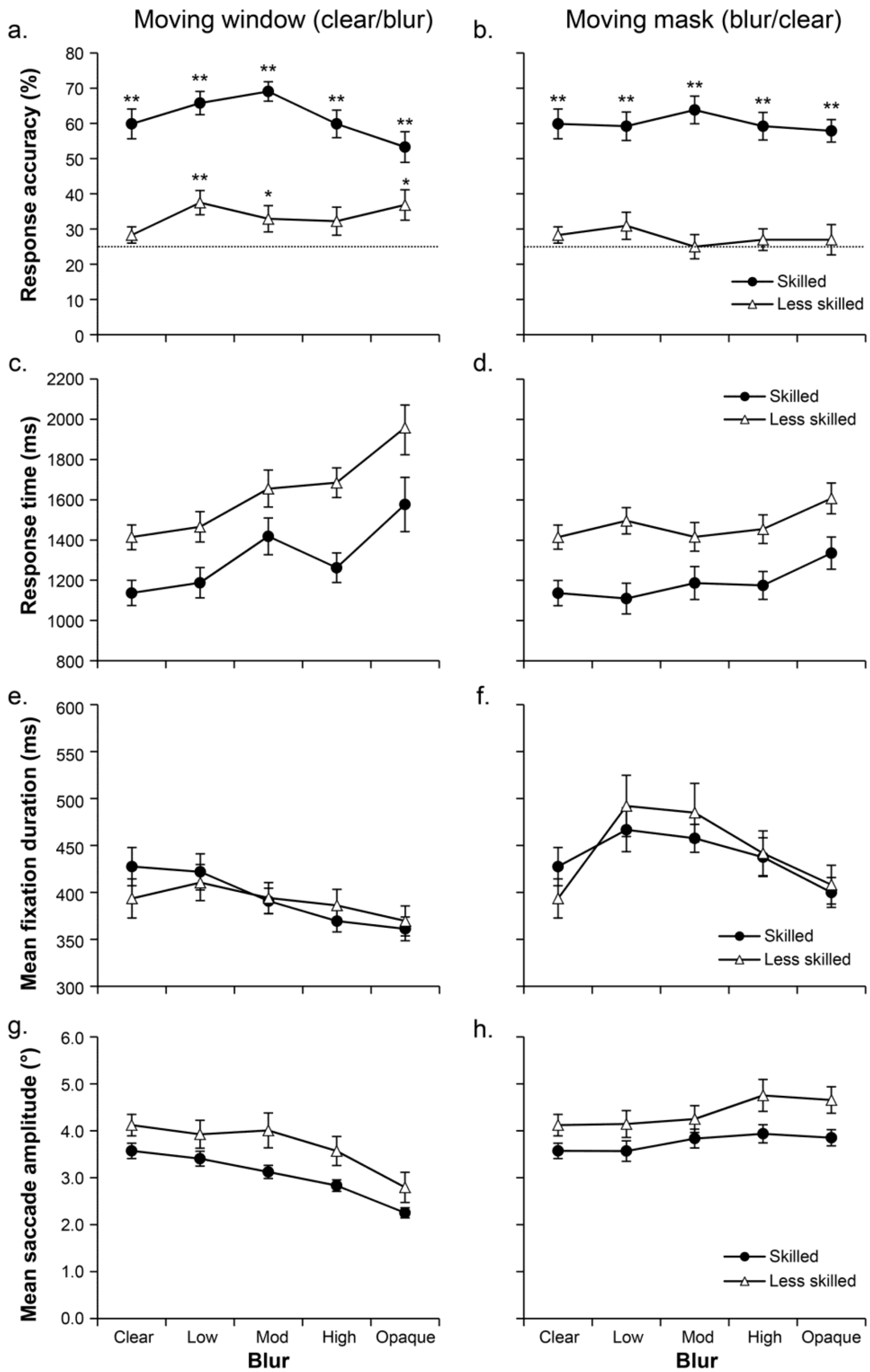

a.
Moving window (clear/blur)
b.
Moving mask (blur/clear)
Response accuracy (%)
0
10
20
30
40
50
60
70
80
**
*
Skilled
Less skilled
c.
d.
Response time (ms)
800
1000
1200
1400
1600
1800
2000
2200
e.
f.
Mean fixation duration (ms)
300
350
400
450
500
550
600
g.
h.
Mean saccade amplitude (°)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
Clear
Low
Mod
High
Opaque
Blur

Figure 3

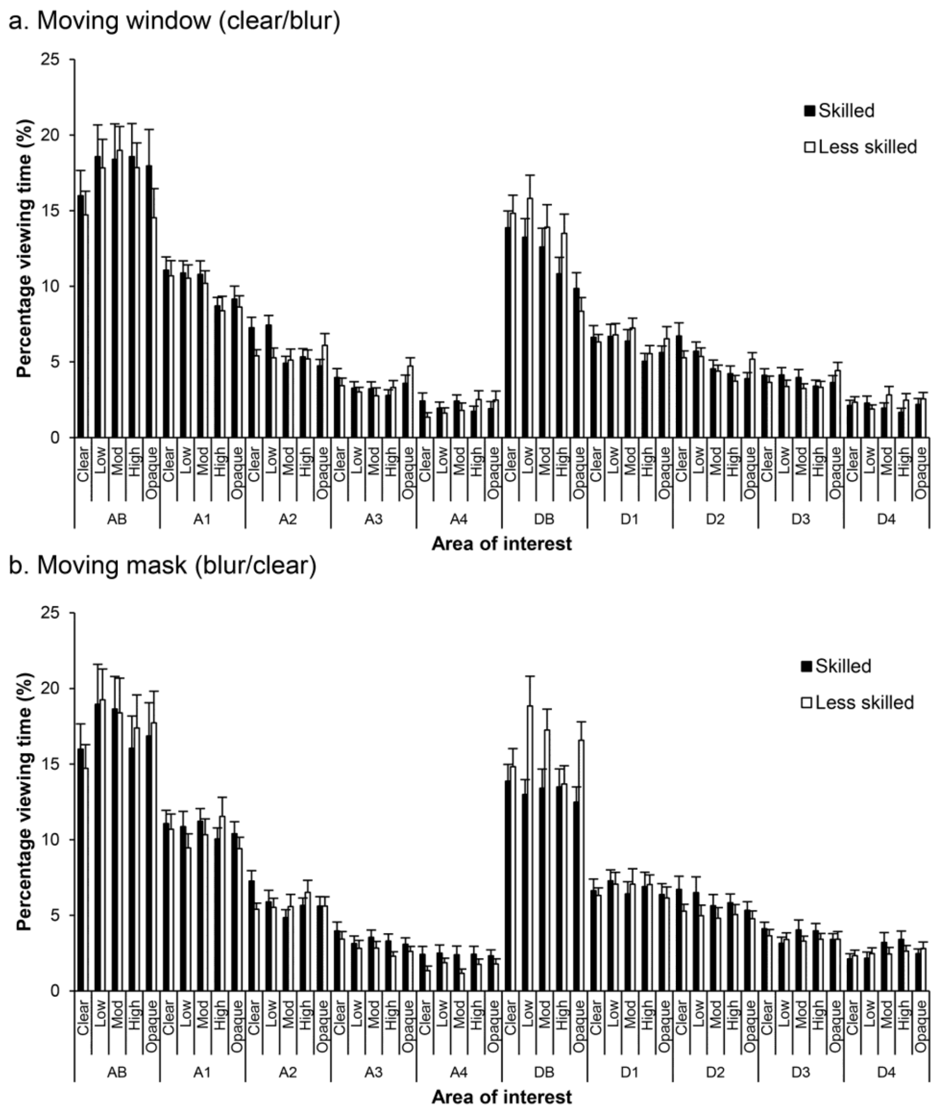

a. Moving window (clear/blur)
b. Moving mask (blur/clear)
Percentage viewing time (%)
Area of interest
Skilled
Less skilled
Clear
Low
Mod
High
Opaque
AB
A1
A2
A3
A4
DB
D1
D2
D3
D4

Figure 4

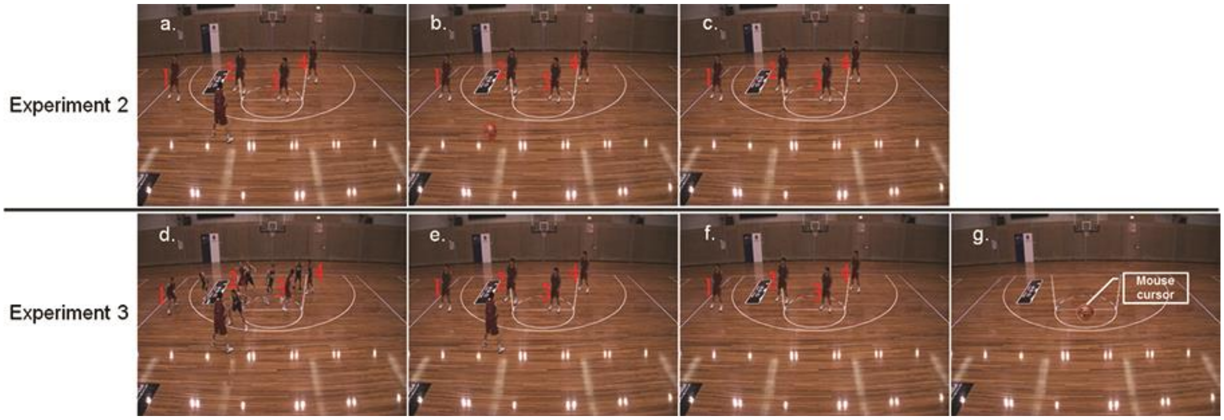


Figure 5

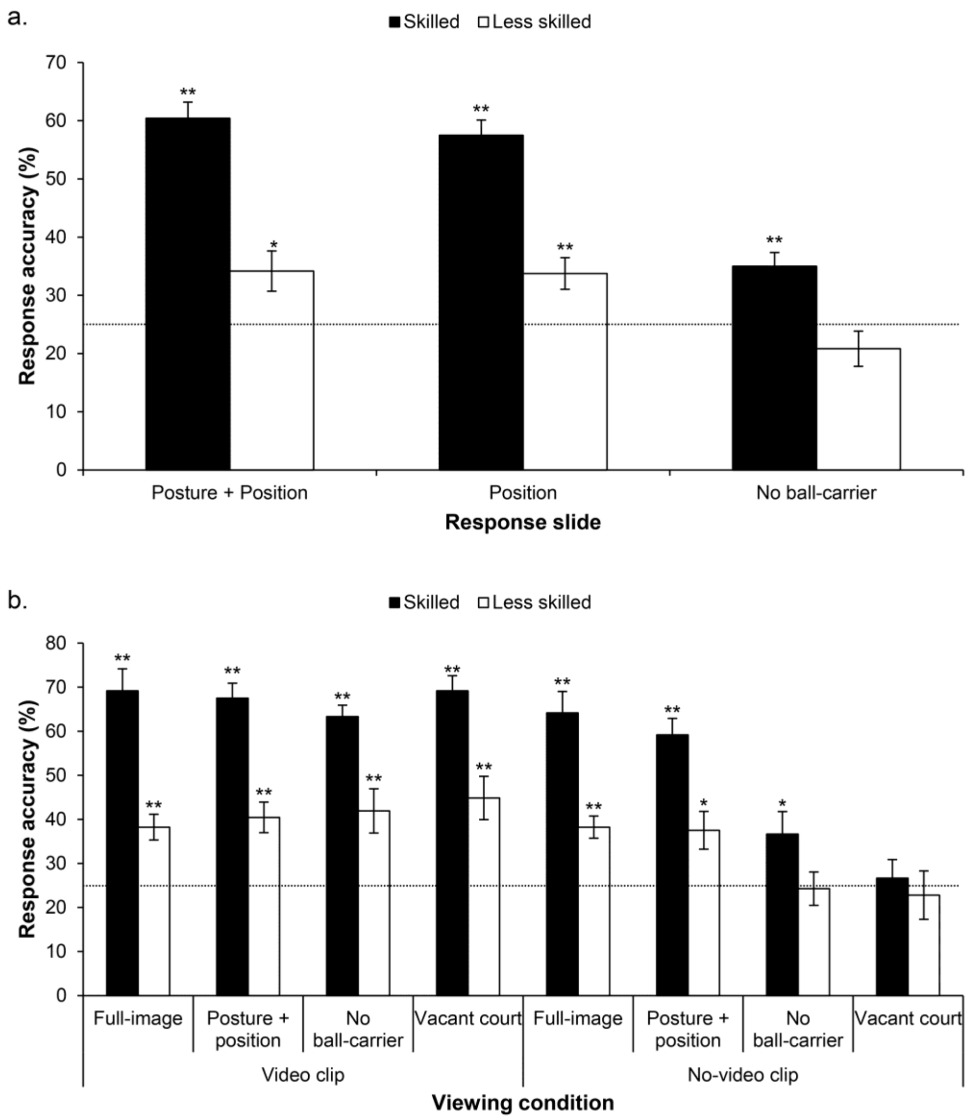

a.
Skilled
Less skilled
Response accuracy (%)
0
10
20
30
40
50
60
70
**
*
**
**
**
Posture + Position
Position
No ball-carrier
Response slide
b.
Skilled
Less skilled
Response accuracy (%)
0
10
20
30
40
50
60
70
80
Full-image
Posture + position
No ball-carrier
Vacant court
Full-image
Posture + position
No ball-carrier
Vacant court
Video clip
No-video clip
Viewing condition

Figure 6

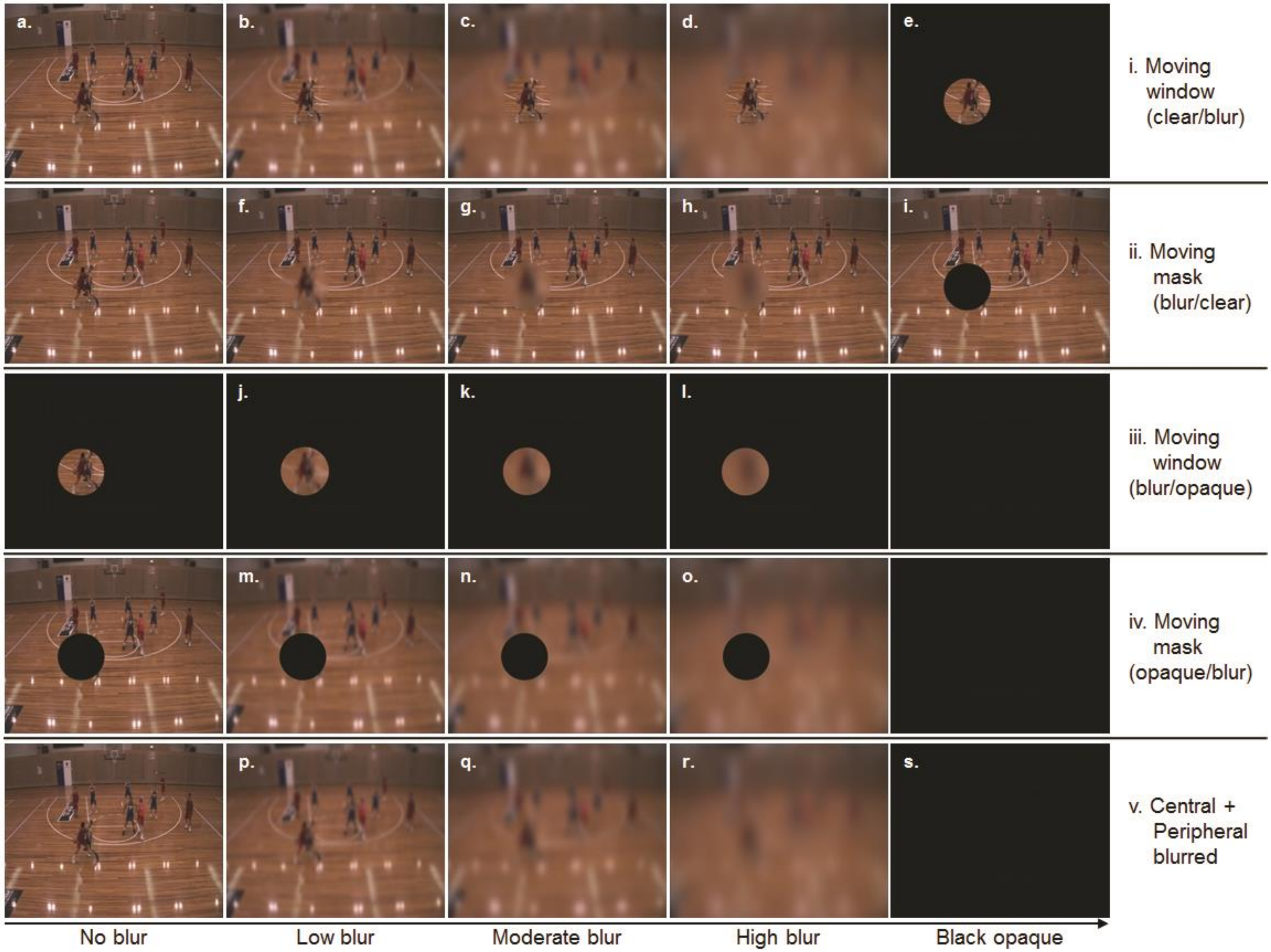

a.
b.
c.
d.
e.
i. Moving window (clear/blur)
f.
g.
h.
i.
ii. Moving mask (blur/clear)
j.
k.
l.
iii. Moving window (blur/opaque)
m.
n.
o.
iv. Moving mask (opaque/blur)
p.
q.
r.
s.
v. Central + Peripheral blurred
No blur
Low blur
Moderate blur
High blur
Black opaque

Figure 7

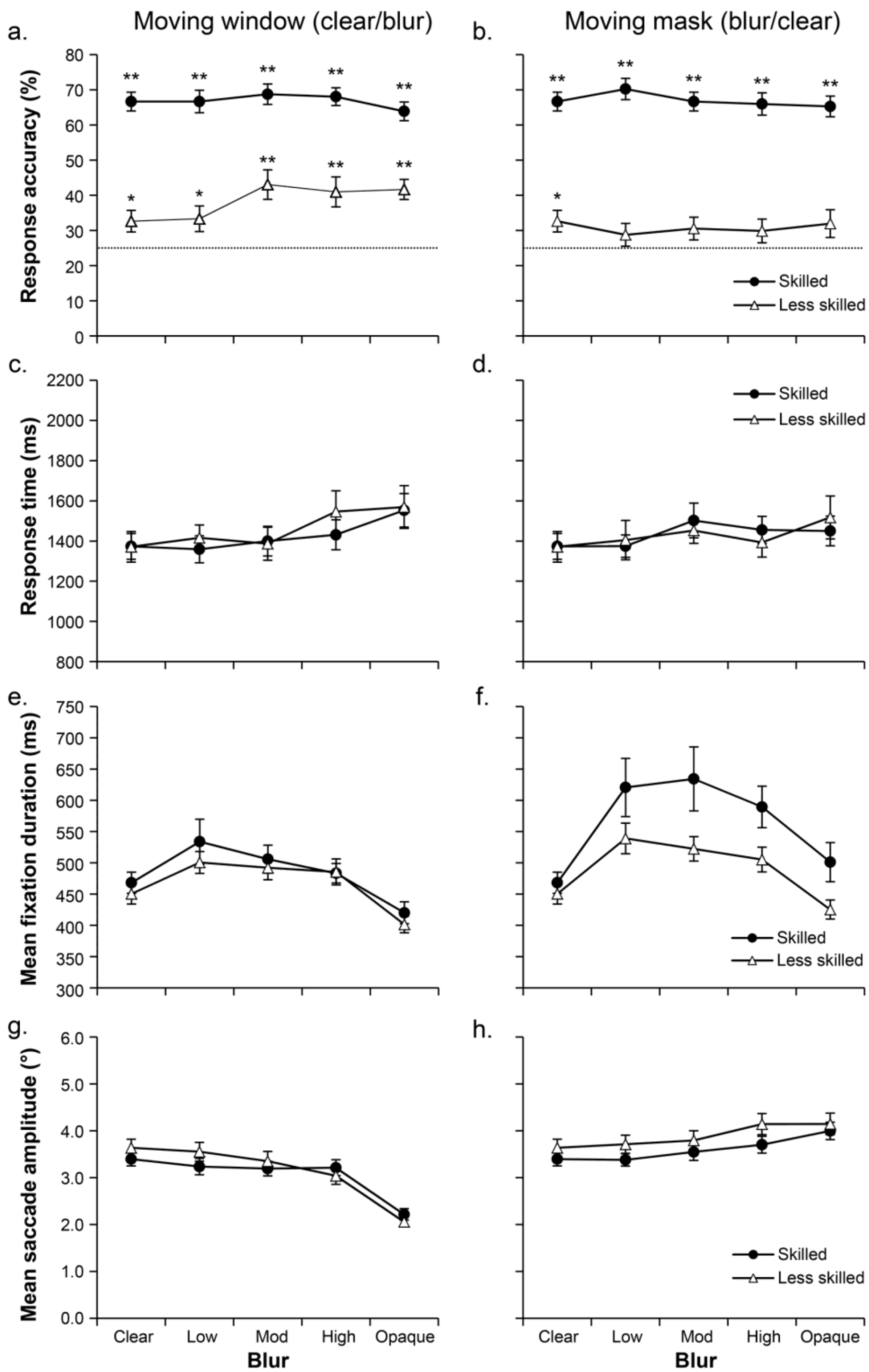

Moving window (clear/blur)
Moving mask (blur/clear)
a.
b.
c.
d.
e.
f.
g.
h.
Response accuracy (%)
Response time (ms)
Mean fixation duration (ms)
Mean saccade amplitude (°)
Skilled
Less skilled
Clear
Low
Mod
High
Opaque
Blur

Figure 8

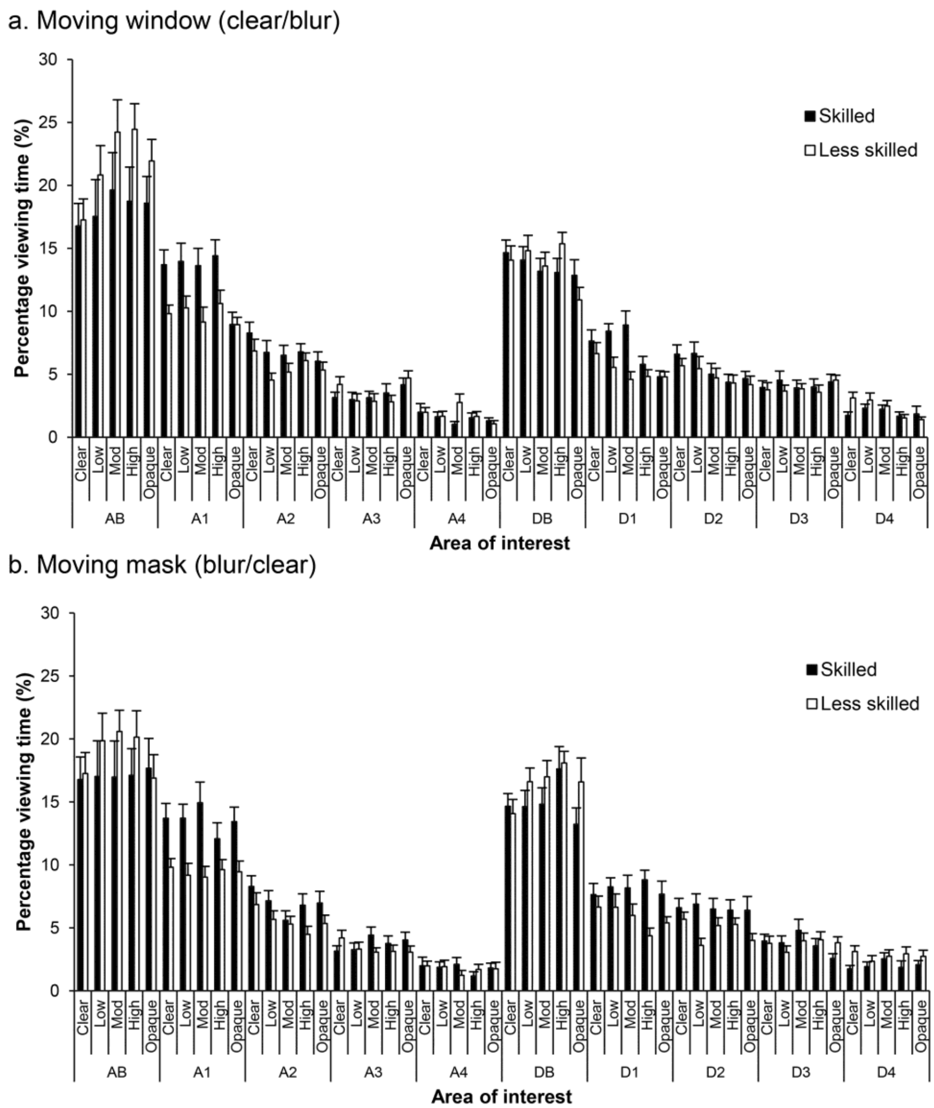

a. Moving window (clear/blur)
Percentage viewing time (%)
0
5
10
15
20
25
30
Skilled
Less skilled
Clear
Low
Mod
High
Opaque
AB
A1
A2
A3
A4
DB
D1
D2
D3
D4
Area of interest
b. Moving mask (blur/clear)
Percentage viewing time (%)
0
5
10
15
20
25
30
Skilled
Less skilled
Clear
Low
Mod
High
Opaque
AB
A1
A2
A3
A4
DB
D1
D2
D3
D4
Area of interest

Figure 9

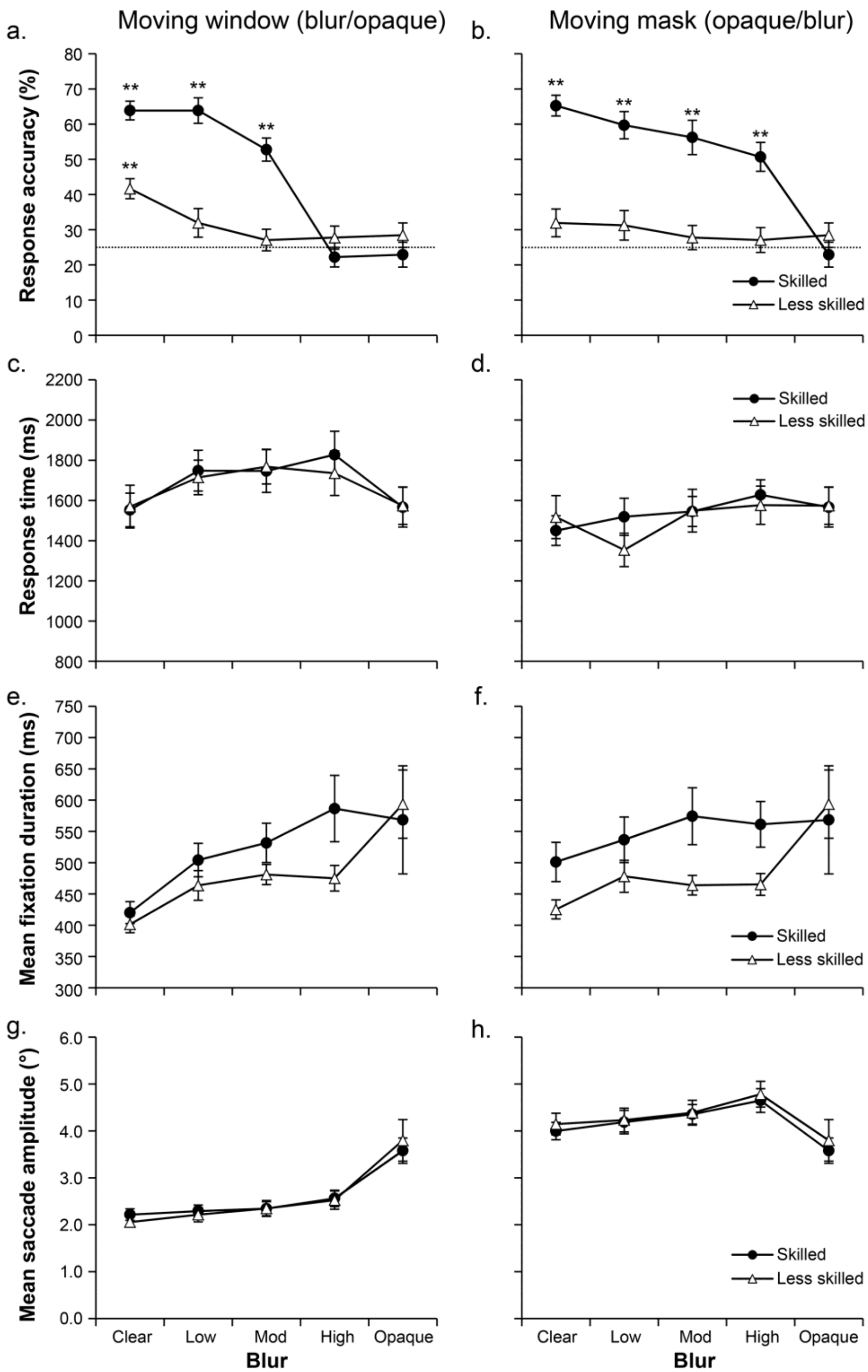

a.
Moving window (blur/opaque)
b.
Moving mask (opaque/blur)
Response accuracy (%)
**
Skilled
Less skilled
c.
d.
Response time (ms)
e.
f.
Mean fixation duration (ms)
g.
h.
Mean saccade amplitude (°)
Clear
Low
Mod
High
Opaque
Blur

Figure 10

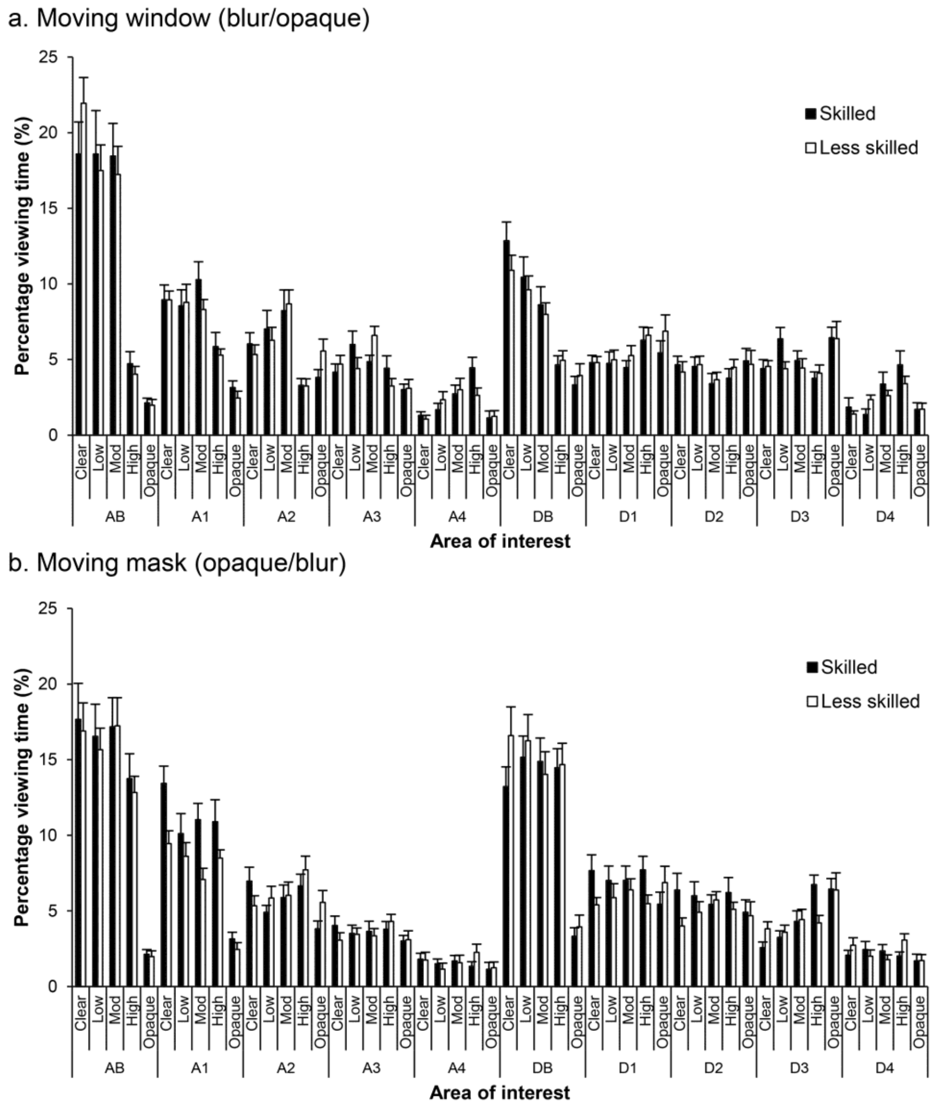
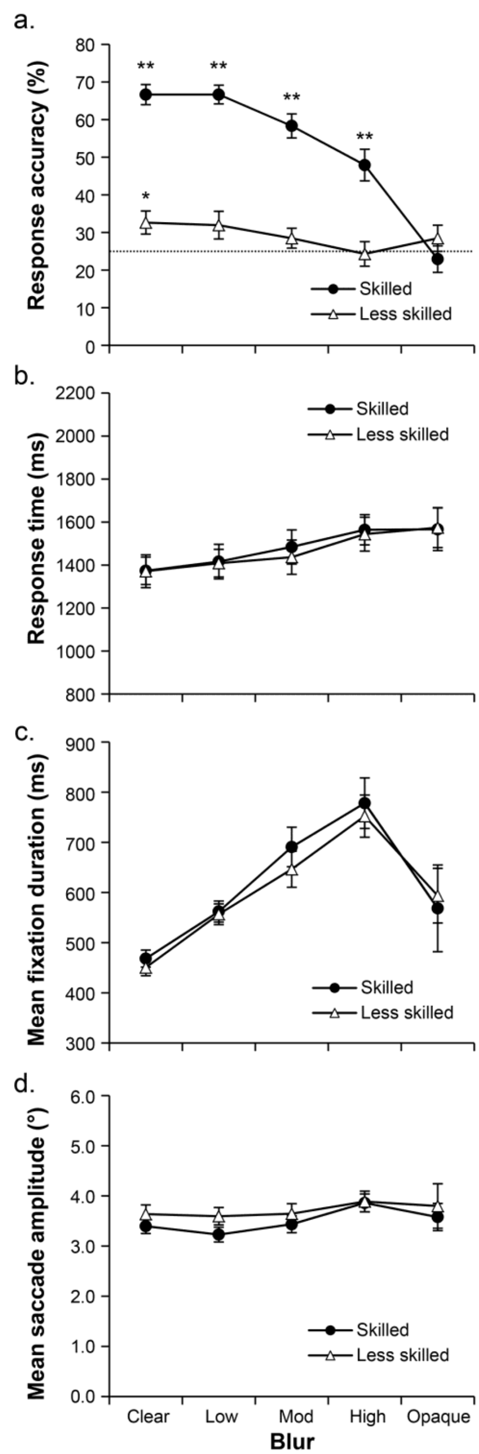

a. Moving window (blur/opaque)
Percentage viewing time (%)
Skilled
Less skilled
Clear
Low
Mod
High
Opaque
AB
A1
A2
A3
A4
DB
D1
D2
D3
D4
Area of interest
b. Moving mask (opaque/blur)
Percentage viewing time (%)
Skilled
Less skilled
Area of interest

Figure 11


a.
Response accuracy (%)
0
10
20
30
40
50
60
70
80
**
**
**
**
*
Skilled
Less skilled
b.
Response time (ms)
800
1000
1200
1400
1600
1800
2000
2200
Skilled
Less skilled
c.
Mean fixation duration (ms)
300
400
500
600
700
800
900
Skilled
Less skilled
d.
Mean saccade amplitude (°)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
Skilled
Less skilled
Clear
Low
Mod
High
Opaque
Blur