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Gaze-contingent training enhances perceptual skill acquisition

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The purpose of this study was to determine whether decision-making skill in perceptual-cognitive tasks could be enhanced using a training technique that impaired selective areas of the visual field. Recreational basketball players performed perceptual training over 3 days while viewing with a gaze-contingent manipulation that displayed either (a) a moving window (clear central and blurred peripheral vision), (b) a moving mask (blurred central and clear peripheral vision), or (c) full (unrestricted) vision. During the training, participants watched video clips of basketball play and at the conclusion of each clip made a decision about to which teammate the player in possession of the ball should pass. A further control group watched unrelated videos with full vision. The effects of training were assessed using separate tests of decision-making skill conducted in a pretest, posttest, and 2-week retention test. The accuracy of decision making was greater in the posttest than in the pretest for all three intervention groups when compared with the control group. Remarkably, training with blurred peripheral vision resulted in a further improvement in performance from posttest to retention test that was not apparent for the other groups. The type of training had no measurable impact on the visual search strategies of the participants, and so the training improvements appear to be grounded in changes in information pickup. The findings show that learning with impaired peripheral vision offers a promising form of training to support improvements in perceptual skill.

Introduction

Perceptual-cognitive skill underpins expertise in many dynamic tasks (Abernethy, Thomas, & Thomas, 1993). For instance, highly skilled basketball players possess refined perceptual-cognitive skills such as the ability to anticipate the actions of others at an earlier point in time (*anticipatory skill*; Jones & Miles, 1978), a capacity to perceive and recall previously seen patterns of play (*pattern recall*; Chase & Simon, 1973), and the ability to select the most appropriate response from a variety of possible options (*decision making*[1]; Allard, Graham, & Paarsalu, 1980; Allard & Starkes, 1980). In externally paced dynamic activities common in sport (Abernethy, 1991; Williams & Davids, 1998) and other activities such as driving (Crundall, Underwood, & Chapman, 1999) and aviation (Bellenkes, Wickens, & Kramer, 1997), effectual perceptual-cognitive skill requires the performer to account for rapidly changing visual information that is located across the breadth of the visual field. As a result, peripheral vision is likely to play a significant role in perceptual-cognitive performance. For example, when driving, eminent hazards are typically first detected using peripheral vision, and the driver subsequently redirects their central vision toward the hazard to assess the risk using visual information of higher resolution (Crundall et al., 1999). Similarly, skilled athletes have been presumed

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to use their peripheral vision to rapidly extract information about the relative position of other players to guide decision making and interactions with the environment (e.g., Abernethy, 1991; Williams & Davids, 1998). As a result, the development of expertise in these dynamic tasks is likely to rely on a substantial advantage in the use of peripheral vision.

In a series of recent experiments, we have shown that skilled athletes *are* better able to make use of their peripheral vision when performing a domain-specific task (Ryu, Abernethy, Mann, & Poolton, 2015; Ryu, Abernethy, Mann, Poolton, & Gorman, 2013). In those studies, the decision-making ability of skilled and less-skilled basketball players was tested when viewing video footage of basketball game scenarios. A gaze-contingent display was used to change the visual display—in real time—depending on where the observer was looking (McConkie & Rayner, 1975; Rayner & Bertera, 1979), and at critical moments in the play, the video stopped and participants were required to select which teammate was best positioned to receive a pass from the player holding the ball. Participants viewed the video clips in each of three conditions: a *moving-window* condition, in which a clear window was centered on the point of fixation but blurred elsewhere; a *moving-mask* condition, in which central vision was blurred so that only peripheral vision was clear; and a full-vision *control* condition, in which vision was unperturbed. The skilled group demonstrated superior decision-making performance irrespective of the visual condition, highlighting a better capacity to use both their central *and* peripheral vision when performing the decision-making task. In contrast, when viewing with only peripheral vision, the performance of the lesser-skilled players was reduced to a level that was no better than that achievable by guessing, demonstrating their lack of capacity to use information located in their peripheral field.

The findings of the studies by Ryu et al. (2013, 2015) are consistent with the idea that lesser-skilled performers experience *perceptual narrowing* when performing a task they are less familiar with (in that case, basketball decision making). Perceptual narrowing (Easterbrook, 1959; Weltman & Egstrom, 1966) refers to the idea that the increase in stress and/or arousal that might be expected when performing an unfamiliar task will reduce an observer's ability to attend to items located in their visual periphery. In essence, perceptual narrowing is thought to restrict attention to the central portion of the visual field, at least in part to increase the ability to attend to central processing demands. Although it is unclear whether there is an actual narrowing of vision (akin to tunnel vision) or whether there is a more general reduction of sensitivity throughout the periphery (see Crundall, Underwood, & Chapman, 2002, for a discussion), it is clear that stress or arousal can alter the ability to attend to and perceive information located in the visual periphery. Crucially, reductions in peripheral sensitivity are known to have important practical consequences. For example, the incidence of motor vehicle accidents is higher in elderly people who score poorly on an assessment of the Useful Field of View, a test designed to assess the ability to identify and localize suprathreshold targets in the visual periphery (Clay et al., 2005; Owsley, Ball, Sloane, Roenker, & Bruni, 1991).[2]

Given the role played by peripheral vision in the development of competence (and expertise) in dynamic tasks, it seems reasonable to question whether the rate at which one can learn to use peripheral vision can be enhanced as a result of perceptual training. The general benefits of perceptual training programs designed to enhance perceptual-cognitive skills (such as anticipatory skill and decision making) have been known for more than 50 years (e.g., Abernethy, Wann, & Parks, 1998; Damron, 1955; Ward et al., 2008). Early studies sought to formally guide the attention of learners in a very prescriptive way (e.g., Abernethy, Wood, & Parks, 1999; Farrow, Chivers, Hardingham, & Sachse, 1998), usually incorporating explicit instructions based on expert models of how the task should be performed, in the process developing declarative knowledge about how and from where the learner should extract critical information. However, there has been a growing awareness of the limitations of these training programs and the types of outcomes they might produce. Recent approaches have relied on more implicit means of training (e.g., Smeeton, Williams, Hodges, & Ward, 2005; Farrow & Abernethy, 2002; although see Farrow & Abernethy, 2003; Jackson, 2003) to enhance skill retention without developing explicit knowledge about the underlying information used to perform the task (Jackson & Farrow, 2005). For instance, the color-cueing training approach uses video-based tasks in which a colored highlight is incorporated into the video to guide the observer's central vision toward the critical informative cues/areas that skilled performers would use, without necessarily providing explicit rules on how to use that information (Grant & Spivey, 2003; Hagemann, Strauss, & Cañal-Bruland, 2006; Ryu, Kim, Abernethy, & Mann, 2013; Savelsbergh, van Gastel, & van Kampen, 2010; Wilson et al., 2011). However, these perceptual training approaches have focused largely on the role of central vision in the development of perceptual-cognitive skill, and as a result, very little is known about whether perceptual training can be used to enhance the usefulness of peripheral vision and, if so, what might be the most effective means of doing so.

In an effort to enhance the ability to use peripheral vision when performing perceptual-cognitive tasks, one possible approach could be to use a gaze-contingent display to selectively present information to only one particular segment of the visual field during training.

The most intuitive gaze-contingent approach to improve the ability to use peripheral vision would be one that removes central vision so that learners must become accustomed to using the outer (peripheral) segment of their visual field. The success of this approach, however, relies on the assumption that the training benefits are likely to be specific to the area of the visual field that is trained (*specificity of training*; Henry, 1968; Proteau, 1992). If decision-making skills were to transfer across the different segments of the visual field, then it may be that an approach that trains decision-making skill using central vision will be just as (or more) effective than one that selectively trains peripheral vision, particularly if exposing the learner to the central processing demands of the perceptual task from the onset of training helps moderate perceptual narrowing.

The training of central vision can of course take place when viewing with the full visual field; however, there is reason to believe that a gaze-contingent approach that *removes* peripheral vision might actually prove to be, counterintuitively, the most efficacious means of improving decision making in the peripheral visual field. The development of perceptual-cognitive skill requires learners to attend to the most pertinent information within a given scenario while ignoring the less relevant information (Abernethy & Russell, 1987). Given that most of the less-relevant information is likely to be located in the peripheral visual field (Ryu et al., 2015), it could be that the removal of peripheral vision draws the attention of lesser-skilled performers toward the more central cues that skilled performers would typically rely on. In support, the study by Ryu et al. (2015) of skilled and less-skilled basketball players found that lesser-skilled players *improved* their decision making when a gaze-contingent display was used to blur the visual periphery. It was hypothesized that the peripheral blur may have improved information pickup by means of enforced perceptual narrowing, whereby the concurrent demands and distractions in peripheral vision were attenuated, permitting an increased attentional focus on the critical centrally fixated cues (Reingold, Loschky, McConkie, & Stampe, 2003). Indeed, the peripheral blur led the less-skilled players to increase the time they spent fixating the ball carrier, a critical cue heavily relied on by skilled performers. In that study, however, there was a *temporary* improvement in decision-making performance in the presence of peripheral blur, and it remains unclear whether there might be longer-term benefits of *training* with peripheral blur whereby any improvements in decision making are retained in the absence of the gaze-contingent peripheral blur.

The aim of this study was to determine whether decision-making skill in perceptual-cognitive tasks could be improved as a result of perceptual training that impaired selective areas of the visual field. We were particularly interested in what might prove to be the best means of improving the ability to use peripheral vision when performing a perceptual-cognitive task. To this end, we assigned participants to one of four training groups: a *moving-window training* group (with clear central vision and blurred peripheral vision), a *moving-mask training* group (with blurred central vision and clear peripheral vision), a *full-vision training* group (unrestricted vision), and a *control* group (who undertook unrelated training with unrestricted vision). To examine the transferability of any training improvements across the different areas of the visual field, participants performed pre, post, and retention tests of decision-making skill when viewing with each of the full visual field, central vision only (moving window), and peripheral vision only (moving mask) conditions. Based on the findings of Ryu et al. (2015), we hypothesized that the *moving-window training* group who trained with blurred peripheral vision would improve their ability to attend to the informative cues within the scenarios and as a result that their training would lead to the best improvement in overall decision making when the gaze-contingent manipulation was removed (allowing participants to view with full vision). Moreover, we hypothesized that the benefits accrued by *moving-window training* would be generalizable across the visual field, that is, that the *moving-window training* group would experience the best possible generalizable improvement in the ability to pick up task-specific information, ultimately ensuring that they should perform best in the posttest and retention test of decision making even when using only their peripheral vision.

Method

Participants

Fifty participants (age: $M = 24.2$ years, $SD = 3.1$; 29 male) with limited recreational basketball experience ($M = 1.4$ years) participated in the study. Ethical approval was obtained from the institutional human research ethics committee prior to testing, with informed consent obtained prior to the commencement of the experiment.

Apparatus

An Eyelink II (SR Research Ltd., Mississauga, Ontario, Canada) was used to record eye movements (250 Hz) and to control the gaze-contingent display. Experiment Builder software (SR Research Ltd.) was

Figure 1. Static screenshot of the (a) full-vision, (b) moving-window, and (c) moving-mask viewing scenarios.

used to facilitate the gaze-contingent presentation of video clips. Three different types of viewing scenarios were used for both the training and tests: (a) full vision, (b) moving window, and (c) moving mask (see Figure 1). The *full-vision* scenario presented normal, unmanipulated video clips with no blurring in either central or peripheral vision. In the *moving-window* viewing scenario, a clear circular window of 5° diameter (see also Ryu et al., 2015; Ryu, Abernethy, et al., 2013) was placed about the point of fixation, and this moved each time the participant altered his or her position of gaze. Visual information available elsewhere in the visual field (i.e., peripheral vision) was degraded with visual blur applied to the video footage using Adobe Premiere CS 4 (Gaussian blur with filter level 50; see Ryu et al., 2015; Adobe Systems Incorporated, San Jose, CA). This level of blur equates to pixel-wise Gaussian blur with a spatial frequency cutoff of 0.5 cycles per degree and has previously been shown to be a level of blur that suitably perturbs information pickup in this task while allowing gaze to be directed toward the areas of interest (AoI) that would usually be prioritized without any gaze-contingent manipulation (see Ryu et al., 2015). In the *moving-mask* scenario, the same level of blur was applied centrally rather than peripherally, with a moving blur mask of 5° diameter around the line of gaze. Using this gaze-contingent 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).

Test and training materials

Decision-making tests

Purposefully filmed video clips of five-on-five basketball play (the same as those used by Gorman, Abernethy, & Farrow, 2012, 2013; see also Ryu et al., 2015; Ryu, Abernethy, et al., 2013), each of approximately 7-s duration, were occluded at a moment when a critical decision was needed by the ball carrier as to which teammate was most appropriately positioned to receive a pass. Three expert coaches collectively rated the extent to which the clip was representative of actual game play and determined the most appropriate decision to make in each scenario. Only clips that were judged to be highly representative and that concluded with a clear best option for the ball carrier were selected for use in the experiment (for more detail, see Gorman, Abernethy, & Farrow, 2011; Gorman et al., 2012). The basic principles for determining the most suitable options for the ball carrier were based on (a) the position of the attacking teammates relative to the ball carrier and (b) the proximity of the teammates to the basket (as players generally aim to pass to a player in a better position to shoot the ball; see experiments 2 and 3 in Ryu et al., 2015).

Sixteen video clips met the criteria for inclusion in the experiment and were mirrored about the vertical axis using Adobe Premiere CS 4 to produce a total set of 32 clips for the decision-making tests (see also Ryu et al., 2015). For each participant, a set of 16 video clips (half original, half mirrored) were selected for use in a pretest with the remaining 16 clips used for a posttest. The set of 16 video clips viewed by participants in the pretest and the posttest was counterbalanced across participants to avoid order effects. A random selection of eight clips from the pretest was matched with the eight remaining clips from the posttest for use in a retention test. At no point was the original and mirrored version of the same video clip shown in the same test (pre, post, or retention). In each of the pre, post, and retention tests, participants watched each of the 16 video clips when they were completely clear (*full vision in test*), when peripheral vision was blurred (using the gaze-contingent moving-window manipulation; *moving window in test*), and when central vision was blurred (using the gaze-contingent moving-mask manipulation; *moving mask in test*). The order of the 48 trials was randomized in each test. The inclusion of the moving-window and -mask conditions in the tests was designed to (a) ensure that the training groups were equated in their ability to selectively use central and peripheral vision prior to the commencement of the training phase of the study and to (b) examine the transferability of the different training interventions to the independent usage of central and/or peripheral vision in the posttest and retention test.

At the conclusion of each test clip, a static response slide was shown consisting of the same basketball court without any players but with a ball positioned at the center of the free-throw line. The position of the ball was controlled by a computer mouse, with the participant's task being to use the mouse to click the position on the court that best represented where the player was standing whom they judged to be best placed to receive the pass (i.e., the position of their feet). The participant's response was established by determining which attacking player was located closest to the position of the mouse click. This was done based on the shortest of the four distances from the screen-based x-y coordinates of the mouse click to the center of the feet of the four attacking teammates (midpoint of the stance). This mode of response has been experimentally established as the most appropriate and neutral response mode to use and one in which there was no inherent advantage for more experienced participants (see Ryu et al., 2015).

Training stimuli

Video footage of National Basketball Association (NBA) games was examined, and suitable clips were selected for inclusion as training stimuli if the visual angle and the structure and dynamics of the game play were similar to that seen in the video clips used in the testing sessions. As in the tests, individual video clips were occluded at a key moment when a pass decision was required. To prevent participant familiarization with the time of occlusion, the duration of the video clips used for training varied from 6 to 12 s. Following editing, an expert coach rated each clip using the same criteria employed to select the testing-session video clips (i.e., the representativeness of real game play and a clear correct response). A total of 144 video clips were selected for use in the training sessions.

Procedures

The experiment consisted of four phases: pretest, training intervention, posttest, and retention test. The pretest took place 1 day prior to the commencement of the training intervention, which itself was held over 3 consecutive days; the posttest took place the day after the training intervention; and the retention test was scheduled 2 weeks after the posttest.

Pretest, posttest, and retention tests

Participants sat 60 cm from the Eyelink II display monitor (60 Hz). The horizontal and vertical extents of the monitor subtended $30^\circ \times 24^\circ$ of visual angle, respectively (screen size $= 338 \times 270$ mm). Following fitting and calibration of the gaze-registration system, an experimenter informed the participant of his or her task. Specifically, participants were told that a series of video clips of five-on-five basketball game play would be shown that would be occluded at a critical decision-making point. Participants were asked to indicate as quickly and as accurately as possible which player was best positioned to receive a pass by clicking the ball-shaped cursor on the precise screen location where the chosen player was standing at the time the video was occluded. Prior to testing, participants were given 15 practice trials to familiarize themselves with the test procedure and with the three types of gaze-contingent manipulations. The practice clips were different from those used in the test proper. Participants then completed 48 test trials (16 trials in each type of test: full vision, moving window, moving mask), with the entire test session, including practice and calibration, taking approximately 40 min to complete. Prior to each trial, participants were asked to direct their gaze toward a black fixation target at the center of the display, and the gaze position was registered to correct for any drift in calibration.

Training intervention

Forty-eight unique video clips were viewed in a random order in each of the three training sessions (a total of 144 training trials). At the conclusion of each clip, participants were asked to respond as they had in the decision-making test; however, unlike in testing, feedback on performance was provided after the participant responded by showing the final frame of the preceding video with the correct answer highlighted.

The 50 participants were randomly assigned to one of four training groups: (a) a *moving-window training* group ($n = 13$), who watched the training clips with clear central vision and gaze-contingent blur in the periphery; (b) a *moving-mask training* group ($n = 12$), who watched the training clips with gaze-contingent central blur and clear peripheral vision; (c) a *full-vision training* group ($n = 13$), who watched the training clips with no gaze-contingent display manipulation; and (d) a *control* group ($n = 12$), who were shown video clips from the NBA "All-Star Slam Dunk" competition in each of the three training sessions without any gaze-contingent display manipulations (and for the same amount of time it took the other groups to watch their video clips, ~25 min). None of the clips viewed by the control group during training included a decision-making component. Following each training session, feedback was provided to the participants in the three training intervention groups regarding their performance during the session (i.e., percentage of correct responses). Each training session, including calibration and feedback, took approximately 40 min to complete.

Dependent variables and data analyses

Performance data

Response accuracy (RA) and response time (RT) were calculated as measures of performance in the pretest, posttest, retention test, and during the training intervention. RA was calculated as the percentage of trials in which the response of the participant matched the response agreed upon by the expert coaches. RT was the mean time (in milliseconds) that elapsed from the moment the clip occluded to the time that the participant's mouse click response was registered by the computer.

Gaze behavior data

To evaluate whether the different training interventions systematically influenced gaze behavior, six dependent variables were calculated. First, to determine whether the duration of the visual fixations changed as a result of the training intervention, the *mean fixation duration* (in milliseconds) was calculated for each trial by averaging the duration of all fixations in that trial. Second, as a proxy assessment for whether the breadth of the search changed as a result of training, the *mean saccadic amplitude* (in degrees of visual angle) was determined by calculating the average angular subtense of all saccades in each trial. Third, to assess whether the training altered *where* participants directed their fixations, the distribution of gaze across 10 distinct areas of interest (AoI) was assessed for each trial by calculating the *percentage of total viewing time* spent viewing each of the 10 areas. The ten AoIs were (a) the player in possession of the ball (the ball carrier), (b) the defender of the ball carrier, (c–f) each of the four attacking team-mates (from closest to furthest from the ball-carrier), and (g–j) the matching defenders of the four attacking teammates (see also Ryu et al., 2015; Ryu, Abernethy et al., 2013). Fourth, we calculated the *breadth of search relative to the ball carrier* to examine how widely participants searched relative to the position of the ball carrier (known to be the most frequently fixated AoI; Ryu et al., 2015) by taking the average of the distance between the direction of gaze and the centroid for the ball carrier for each frame in a trial (in degrees of visual angle). Fifth, the *difference in spatiotemporal gaze pattern* from pretest to posttest and from posttest to retention test was calculated to compare the differences in the position of central gaze between the different tests. The x-y coordinates of gaze were taken for each clip and compared for each frame to the x-y coordinates for the same frame in the corresponding clip (coordinates flipped if the video was flipped). When averaged across frames in each clip, this provided a measure (in degrees of visual angle) of how much the pattern of gaze changed as a result of training. Finally, *gaze entropy* was calculated to assess the degree to which the gaze pattern was organized or randomly distributed across the different tests. For this variable, the number of fixation transitions between the 10 distinct AoIs was first calculated by producing a first-order transition frequency matrix of $p(i \text{ to } j)$, where i represents the AoI before the transition and j represents the AoI after the transition. These matrices were converted to conditional transition probability matrices of $p(j|i)$, which gives a first-order Markov process in which calculations are made of the probability of fixating on the jth AoI if the previous fixation were to be toward the ith AoI (Allsop & Gray, 2014; Ellis & Stark, 1986). The entropy was calculated using Ellis and Stark's (1986) equation:

$$Entropy = -\sum_{i=1}^{n} p(i)\left[\sum_{j=1}^{n} p(j|i)\log_2 p(j|i)\right], \quad i \neq j$$

where $p(i)$ is the zero-order probability of fixating on the ith AoI (based on the percentage of total viewing time toward it), $p(j|i)$ is the conditional probability of viewing AoI j if the previous fixation was on AoI i, and n is the number of AoIs (i.e., 10 in the current study). A higher entropy value represents a greater level of randomness in the visual search.

Statistical analyses

The dependent variables measuring *RA*, *RT*, *mean fixation duration*, *mean saccadic amplitude, breadth of search relative to the ball carrier*, and *gaze entropy* were analyzed using separate 4 (Training group: moving-window training, moving-mask training, full-vision training, control) × 3 (Test occasion: pretest, posttest, retention test) × 3 (Test type: full vision in test, moving window in test, moving mask in test) analyses of variance (ANOVAs) with repeated measures on the last two factors. Separate analyses were used to examine the *difference in spatiotemporal gaze pattern* from pretest to posttest and from posttest to retention test using separate 4 (Training group) × 3 (Test type) ANOVAs with repeated measures on the last factor. The distribution of fixations toward the 10 AoIs (*percentage of total viewing time*) were subject to a 4 (Training group) × 3 (Test occasion) × 3 (Test type) × 10 (AoI) ANOVA with repeated measures on the last three factors. In addition, data collected during the training interventions for performance (*RA* and *RT*) and from the two conventional measures of gaze behavior (*mean fixation duration* and *mean saccadic amplitude*) were subject to a 3 (Training group: moving-window training, moving-mask training, full-vision training) × 3 (Training session: first, second, third) ANOVA with repeated measures on the second factor to check for changes during the training intervention. For all inferential tests, effect sizes were reported as partial eta-squared values and Cohen's d when appropriate, 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 $p = 0.05$.

Results

Decision-making performance before and after training

Response accuracy

The *moving-window training* group was the best performed of all the training groups (training group × test occasion interaction), $F(5.28, 80.97) = 5.10$, $p < 0.001$, $\eta_p^2 = 0.25$; (main effect for test occasion), $F(1.76, 80.97) = 19.82$, $p < 0.001$, $\eta_p^2 = 0.30$. Figure 2 shows that only the performance of the *moving-window training* group improved *both* from pre- to posttest ($p = 0.016$, $d = 0.95$) and from posttest to retention test ($p = 0.022$, $d = 0.43$). The *full-vision training* group improved from pretest to posttest ($p = 0.001$, $d = 1.10$) but not from posttest to retention test ($p = 0.61$, $d = 0.08$). The *moving-mask training* group improved from pretest to posttest ($p = 0.022$, $d = 1.10$) but failed to retain this skill as their RA *decreased* from posttest to retention test ($p = 0.004$, $d = 0.97$). There were no differences in the performance of the *control* group across any of the test occasions ($ps > 0.24$, $ds < 0.33$). There was no difference in the RA between the groups at posttest, $F(3, 46) = 1.34$, $p = 0.27$, $\eta_p^2 = 0.081$; however, clear differences were apparent in the retention test, $F(3, 46) = 5.70$, $p = 0.002$, $\eta_p^2 = 0.27$. Follow-up t tests revealed that at retention, the RA of the *moving-window training* group was superior to that of the *control* group ($p < 0.001$, $d = 1.39$) and the *moving-mask training* group ($p = 0.004$, $d = 1.13$), whereas the performance of the *full-vision training* group was only greater than that of the *control* group ($p = 0.018$, $d = 1.12$). There was no difference in the RA between the *moving-window training* and the *full-vision training* groups in the retention test ($p = 0.23$, $d = 0.36$).

The advantage conferred by *moving-window training* from posttest to retention test was evident for each of the three different test types (no three-way interaction), $F(12, 184) < 1$. Figure 3 (left panel) shows the changes in RA for each of the three test types as a function of time of test and training group. A significant main effect for test type, $F(2, 92) = 23.69$, $p < 0.001$, $\eta_p^2 = 0.34$, highlights that performance, across all of the training groups, was best in the *moving window in test* and worst in the *moving mask in test* (moving window in test > full vision in test, $p < 0.001$, $d = 0.41$; full vision in test > moving mask in test, $p = 0.022$, $d = 0.22$), reinforcing the advantages offered by the moving-window viewing scenario (see Ryu et al., 2015). All other main and interaction effects were nonsignificant ($ps > 0.12$), highlighting that the benefits of moving-window training found at retention held irrespective of whether participants were tested when viewing with central, peripheral, or full vision.

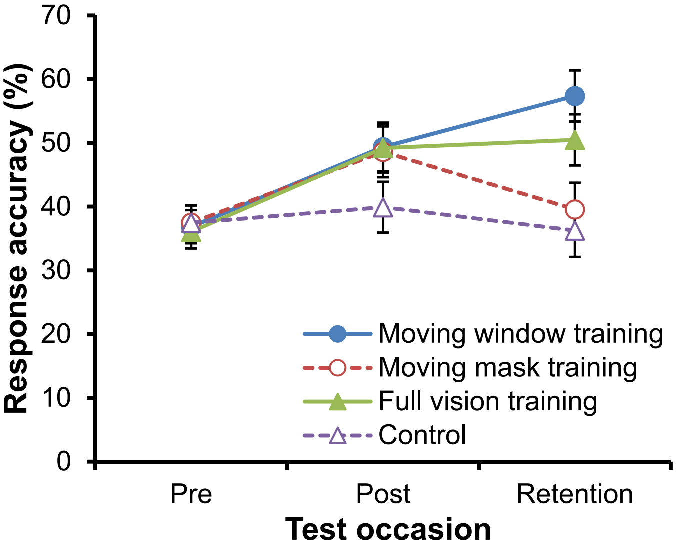


Figure 2. Mean RA of each training group in the pretest, posttest, and retention test. The data represent values of RA collapsed across all three types of test. Error bars indicate the standard error of the mean.

Response time

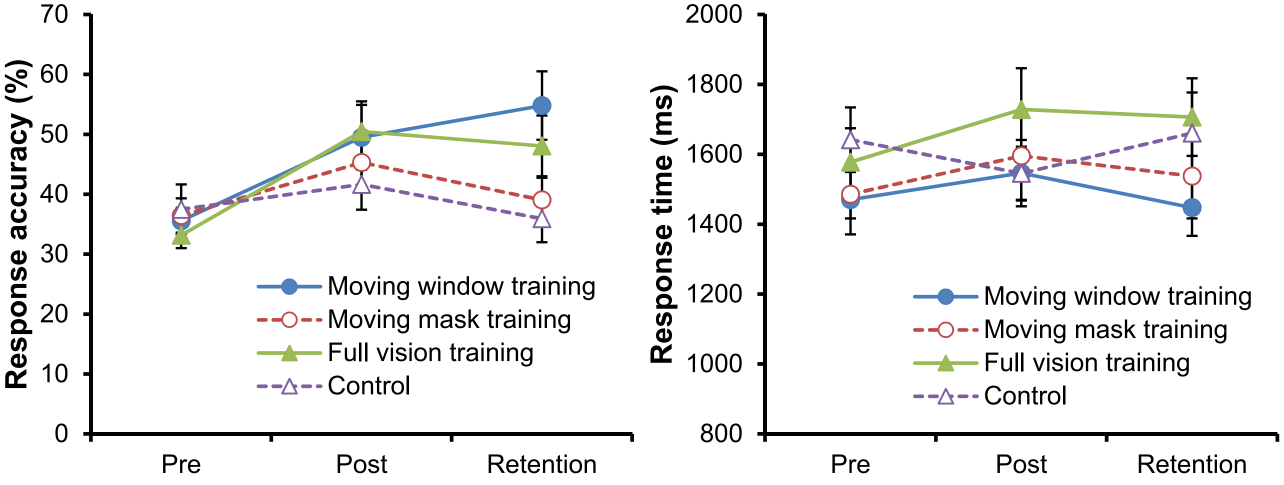
RTs did not change as a result of the training interventions (Figure 3, right panel). There were no main effects for training group, $F(3, 46) < 1$; test occasion, $F(1.55, 71.43) = 2.27$, $p = 0.12$, $\eta_p^2 = 0.05$; or test type, $F(2, 92) = 1.97$, $p = 0.15$, $\eta_p^2 = 0.04$, and no significant interactions between any of those factors ($ps > 0.29$).

Gaze behavior before and after training

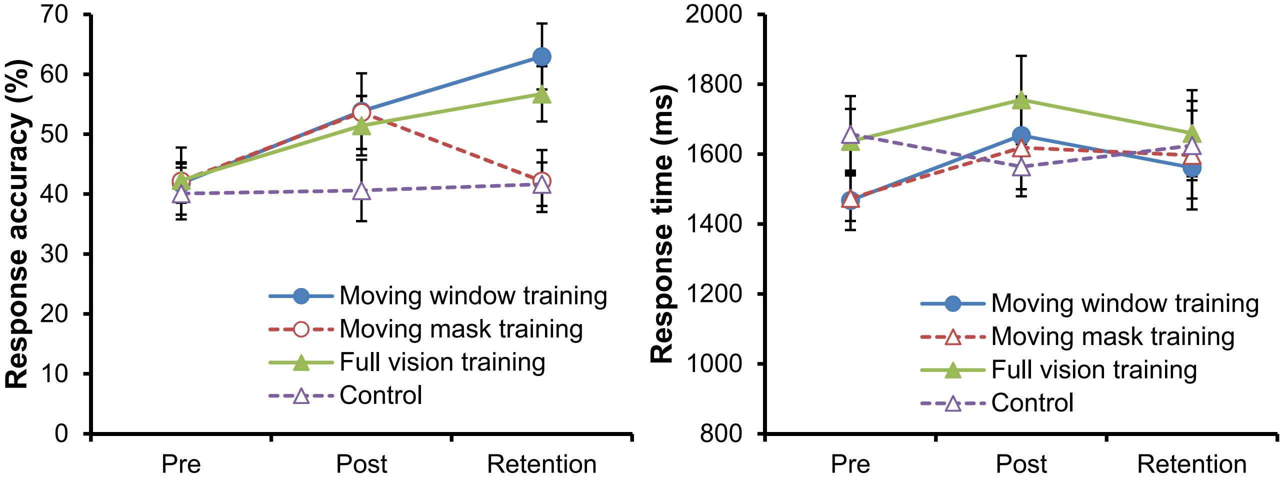
Fixation durations

The type of training performed by participants did not influence the duration of the fixations. Overall, simply taking part in training did result in significant

a. Full vision in test



b. Moving window in test



c. Moving mask in test

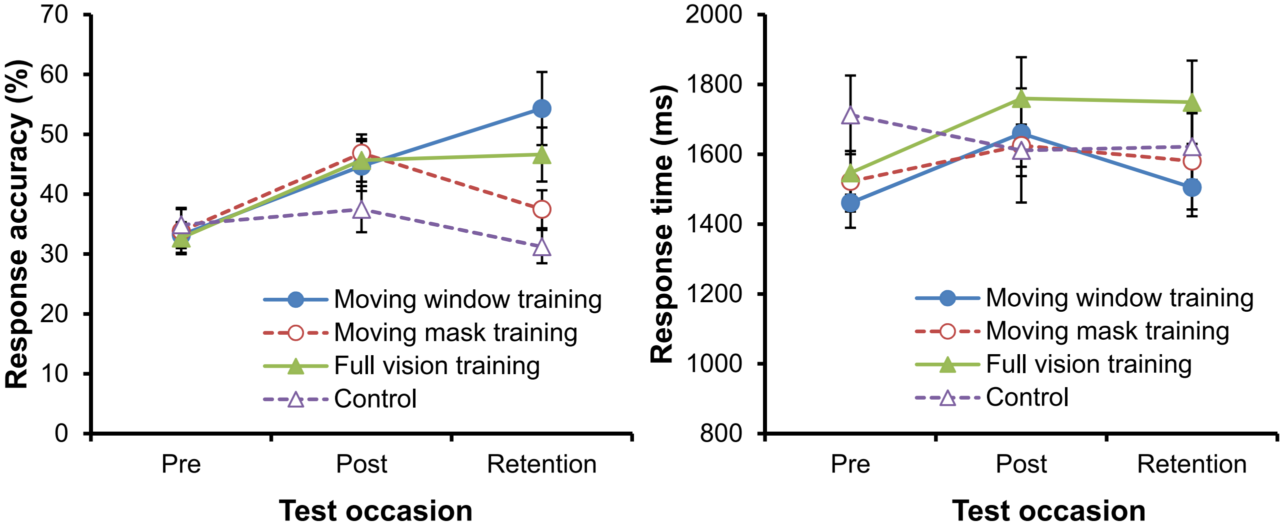


Figure 3. Mean RA (left) and RT (right) for (a) full vision in test, (b) moving window in test, and (c) moving mask in test. Error bars indicate the standard error of the mean.

changes in the duration of fixations (main effect of test occasion), $F(1.40, 64.22) = 37.65$, $p < 0.001$, $\eta_p^2 = 0.45$; however, these changes were not influenced by the nature of the training performed (no test occasion × training group interaction), $F(5.27, 80.77) = 1.53$, $p = 0.19$, $\eta_p^2 = 0.091$ (see Figure 4, left panel). The different test types also influenced the duration of fixations made by participants (main effect of test type), $F(1.40, 64.22) = 37.65$, $p < 0.001$, $\eta_p^2 = 0.45$, and this was affected by test occasion (test type × test occasion interaction), $F(2.66, 122.44) = 4.89$, $p = 0.004$, $\eta_p^2 = 0.096$; (no 3-way interaction), $F(7.99, 122.44) = 1.91$, $p = 0.06$, $\eta_p^2 = 0.11$ (see Figure 5a). Figure 5a summarizes these findings by showing that across all test occasions, the duration of fixations was longer in the *moving mask in test* than in the *moving window in test* ($p < 0.001$, $d = 0.59$), which in turn was longer than those in the *full vision in test* ($p < 0.001$, $d = 0.70$; for similar findings when viewing static images, see Bertera & Rayner, 2000; Loschky & McConkie, 2000, 2002; Nuthmann, 2014). For the *moving mask in test*, the fixation durations increased from pretest to posttest ($p = 0.02$, $d = 0.33$) but not from posttest to retention test ($p = 0.40$, $d = 0.09$). Similarly, for the *full vision in test*, the durations increased from pretest to posttest ($p = 0.04$, $d = 0.29$) but not from posttest to retention test ($p = 0.56$, $d = 0.06$). In the *moving window in test*, the fixation durations did not change across the test occasions (ps > 0.41, ds < 0.12).

Mean saccadic amplitude

The mean saccadic amplitude was not influenced by the type of training performed by the participants. When compared with the *full vision in test* condition, saccadic amplitudes were larger in the *moving mask in test* and smaller in the *moving window in test* (main effect for test type), $F(2, 92) = 55.08$, $p < 0.001$, $\eta_p^2 = 0.55$ (see Figure 4, right panel and Figure 5b; see also for similar findings when viewing static images, Bertera & Rayner, 2000; Loschky & McConkie, 2000, 2002; Nuthmann, 2014). Further, this relationship was moderated by test occasion (test type × test occasion interaction), $F(2.25, 103.65) = 3.12$, $p = 0.042$, $\eta_p^2 = 0.06$ (see Figure 5b). The interaction seemed to be primarily the result of a rather inconsequential increase in saccadic amplitude from pretest to posttest for the full-vision test condition that dissipated by the time of the retention test. The type of training performed by the participants did not moderate any of the relationships (all other main and interaction effects, ps > 0.24).

Percentage viewing time

The analysis of the percentage of total viewing time that was directed toward the 10 AoIs revealed significant main effects for area of interest, $F(1.51, 69.30) = 360.97$, $p < 0.001$, $\eta_p^2 = 0.89$, and for test type, $F(2, 92) = 12.17$, $p < 0.001$, $\eta_p^2 = 0.21$, both of which, however, were overridden by a significant test occasion × test type × AoI interaction, $F(12.35, 567.86) = 2.12$, $p = 0.013$, $\eta_p^2 = 0.04$ (Figure 6). Critically, there were no significant main or interactive effects attributable to training group membership (ps > 0.14). Although the ball carrier attracted most fixations in all test types and at all test occasions, Figure 6 shows that the participants spent proportionally more time directing central gaze toward the ball carrier in the *moving window in test* than for the *full vision in test* ($p < 0.001$, $d = 1.00$) and *moving mask in test* ($p < 0.001$, $d = 0.59$). Participants spent proportionally less time directing their gaze toward the ball carrier in the posttest and retention test in the *full vision in test* (both ps < 0.001, ds > 0.83) and the *moving mask in test* (ps < 0.018, ds > 0.47).

Breadth of search relative to the ball carrier

The type of training performed by participants did not alter the breadth of the search relative to the ball carrier. Training in general increased the breadth of the search from pretest to posttest (pretest: 4.0° ± 0.8°, posttest: 4.3° ± 0.9°; $p = 0.008$, $d = 0.38$), main effect for test occasion, $F(2, 92) = 4.96$, $p = 0.009$, $\eta_p^2 = 0.10$, but there was no change from posttest to retention test (retention test: 4.3° ± 0.8°; $p = 0.71$, $d = 0.16$). In addition, the breadth of the search was significantly greater in the *full vision in test* (4.5° ± 0.7°) than it was in the *moving mask in test* (4.2° ± 0.8°; $p < 0.001$, $d = 0.41$), which, in turn, was greater than that in the *moving window in test* (4.0° ± 0.9°; $p < 0.001$, $d = 0.34$), main effect for test type, $F(1.63, 75.16) = 26.63$, $p < 0.001$, $\eta_p^2 = 0.37$. All other main and interaction effects were nonsignificant (ps > 0.09).

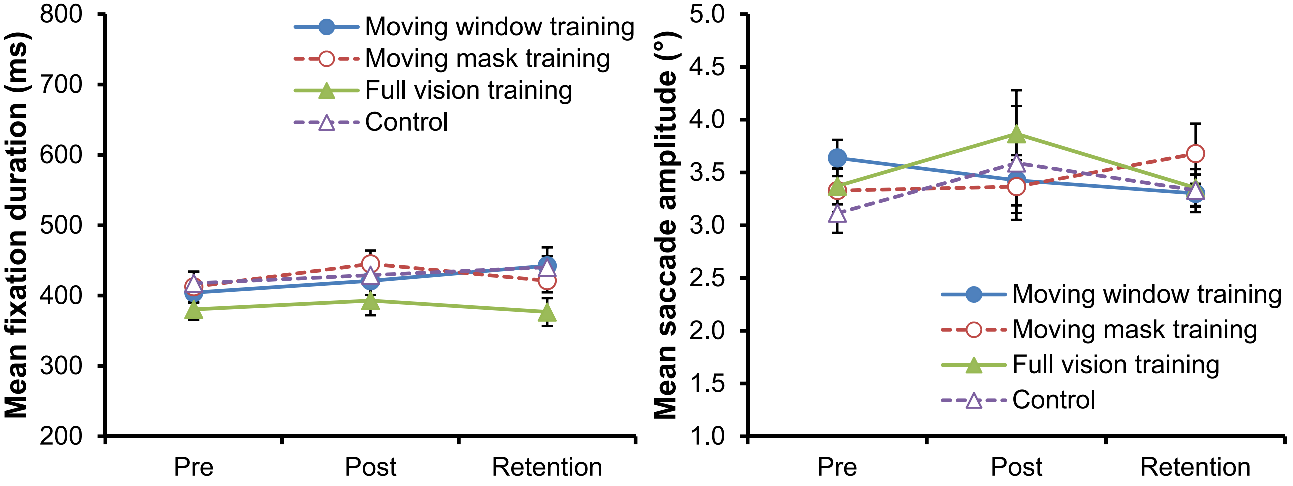
Difference in spatiotemporal gaze pattern

The spatiotemporal gaze pattern did not change from pretest to posttest or from posttest to retention test. There were no main or interaction effects for any of the comparisons of the spatiotemporal gaze pattern (ps > 0.11).

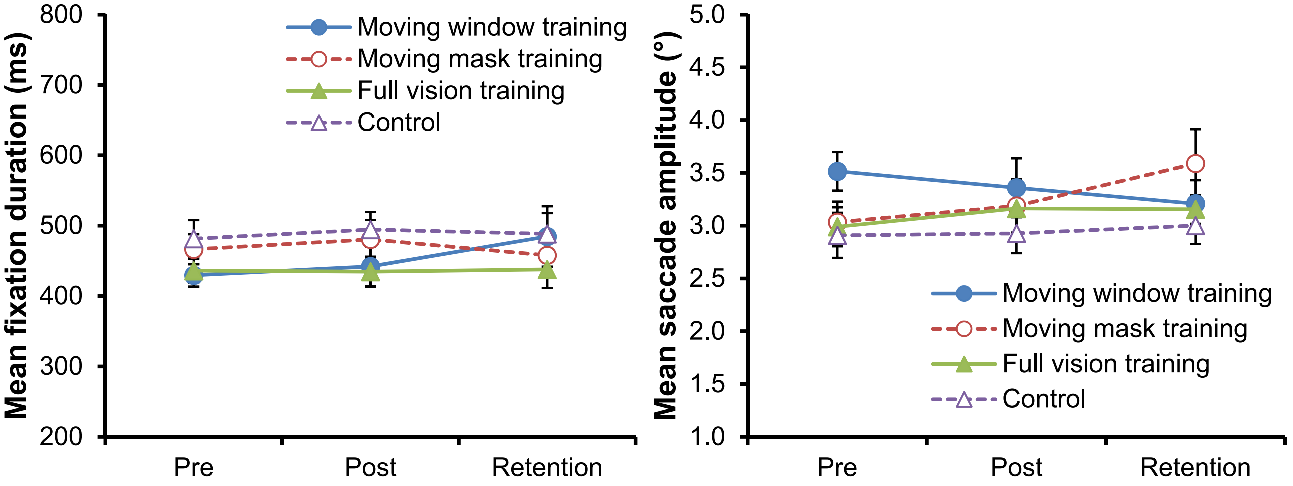
Gaze entropy

The gaze entropy was significantly greater (i.e., gaze was more random) in the *full vision in test* (2.5 bits ±0.2) than it was in the *moving mask in test* (2.3 bits ±0.2; $p < 0.001$, $d = 0.51$), which, in turn, was greater than that in the *moving window in test* (2.2 bits ±0.3; $p < 0.001$, $d = 0.46$), main effect for test type, $F(2, 92) = 61.87$, $p < 0.001$, $\eta_p^2 = 0.57$. However, again, these

a. Full vision in test



b. Moving window in test



c. Moving mask in test

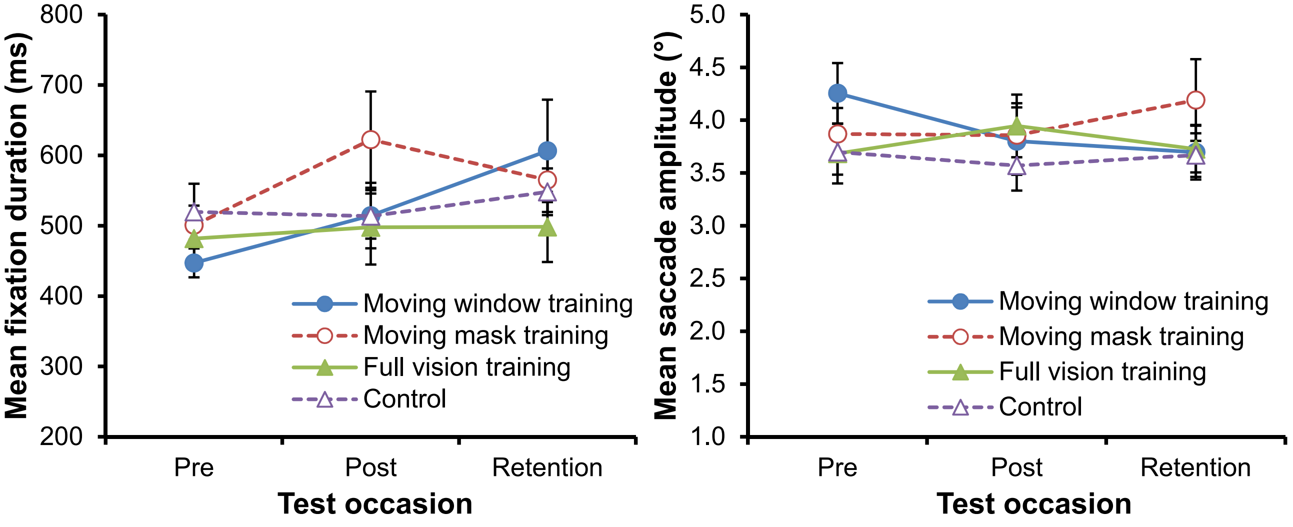


Figure 4. Mean fixation duration (left) and mean saccadic amplitude (right) for (a) full vision in test, (b) moving window in test, and (c) moving mask in test. Error bars indicate the standard error of the mean.

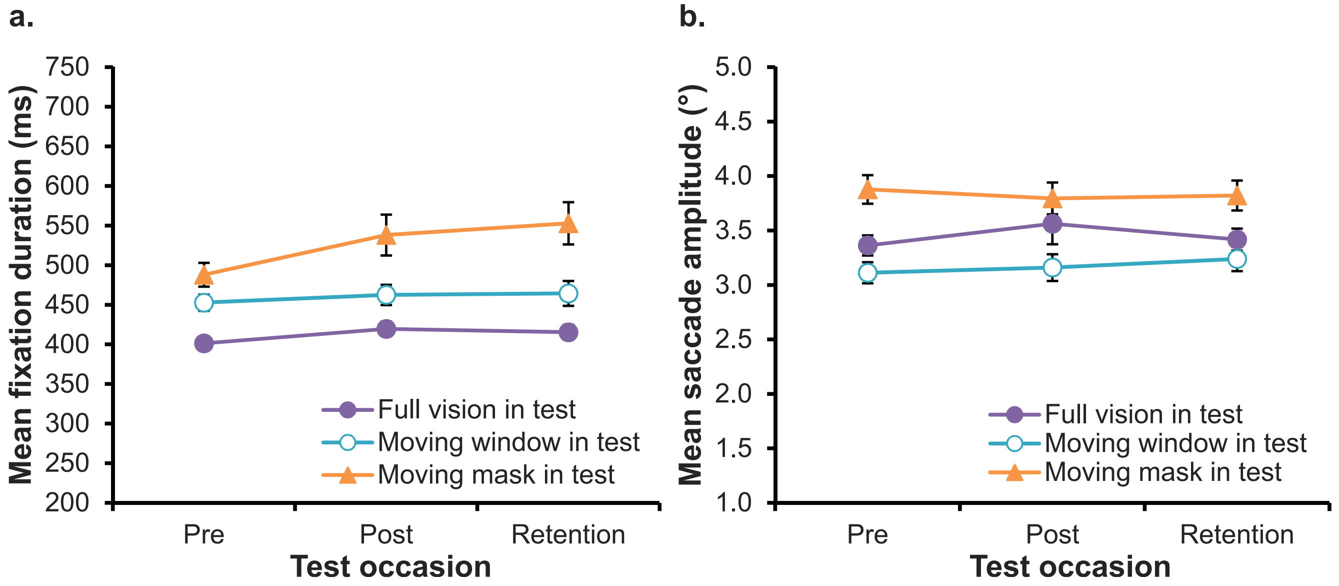


Figure 5. Mean (a) fixation duration and (b) saccadic amplitude for each test type in the pretest, posttest, and retention test. Error bars indicate the standard error of the mean.

effects were not influenced by the type of training undertaken by the participants (all other main and interaction effects were nonsignificant, $ps > 0.07$).

Performance and gaze behavior *during* the 3-day training interventions

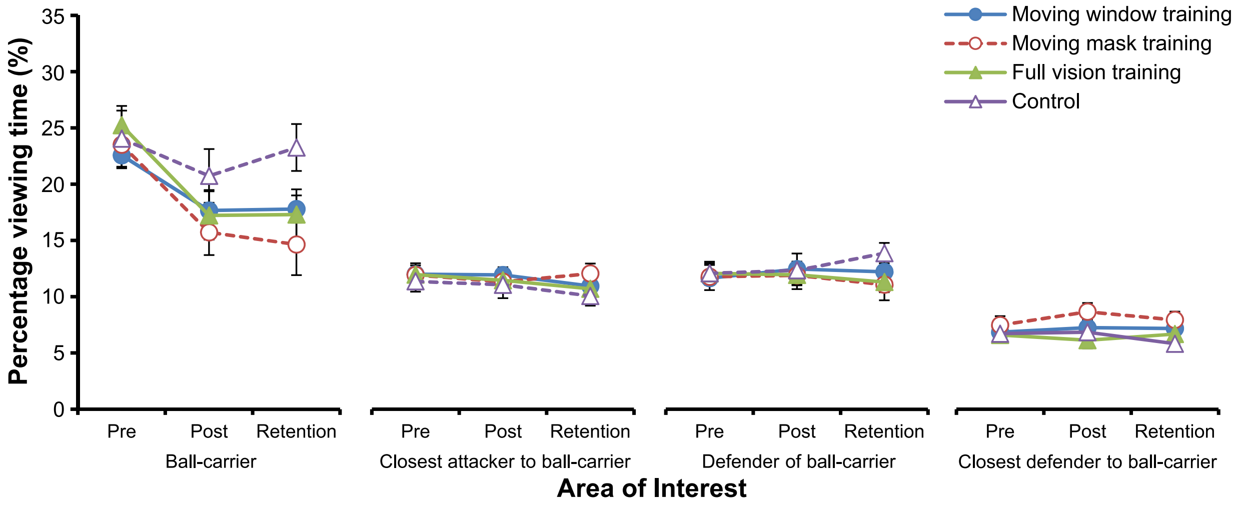
All results reported to this point compare performance before and after the training intervention. We now turn to a consideration of the results found *during* the 3-day training interventions. Figure 7a shows that, as would be expected, the RA increased as a result of training (main effect for training session), $F(2, 70) = 4.94$, $p < 0.01$, $\eta_p{}^2 = 0.12$, and that, consistent with the training group improvements observed from pretest to posttest, these increases were not moderated by the type of training performed by participants (no training group × training session interaction), $F(4, 70) < 1$. During the training, the *full-vision training* group performed better than the *moving-mask training* group ($p = 0.006$, $d = 0.96$; main effect for training group), $F(2, 35) = 5.69$, $p = 0.007$, $\eta_p{}^2 = 0.25$, whereas the RAs of the *full-vision training* and *moving-window training* groups were not different ($p = 0.12$, $d = 0.70$). The RTs (Figure 7b) did not change as a result of training (no main effect of training session), $F(1.67, 58.48) = 1.63$, $p = 0.208$, $\eta_p{}^2 = 0.04$, and did not differ between the training groups (no main effect for training group), $F(2, 35) < 1$; (no interaction between training group and training session), $F(3.34, 54.48) < 1$.

Figure 7c shows that the mean fixation duration of the *moving-mask training* group was significantly longer than that for the *full-vision training* and *moving-window training* groups ($ps < 0.004$, $ds > 0.85$), (main effect for training group), $F(2, 35) = 7.14$, $p = 0.003$, $\eta_p{}^2 = 0.29$; however, these differences did not change as a result of the training (no main effect for training session and no training group × training session interaction, both $Fs < 1$). The mean saccadic amplitude (Figure 7d) did not change during the training interventions and did not differ between the training groups (all $Fs < 1$).

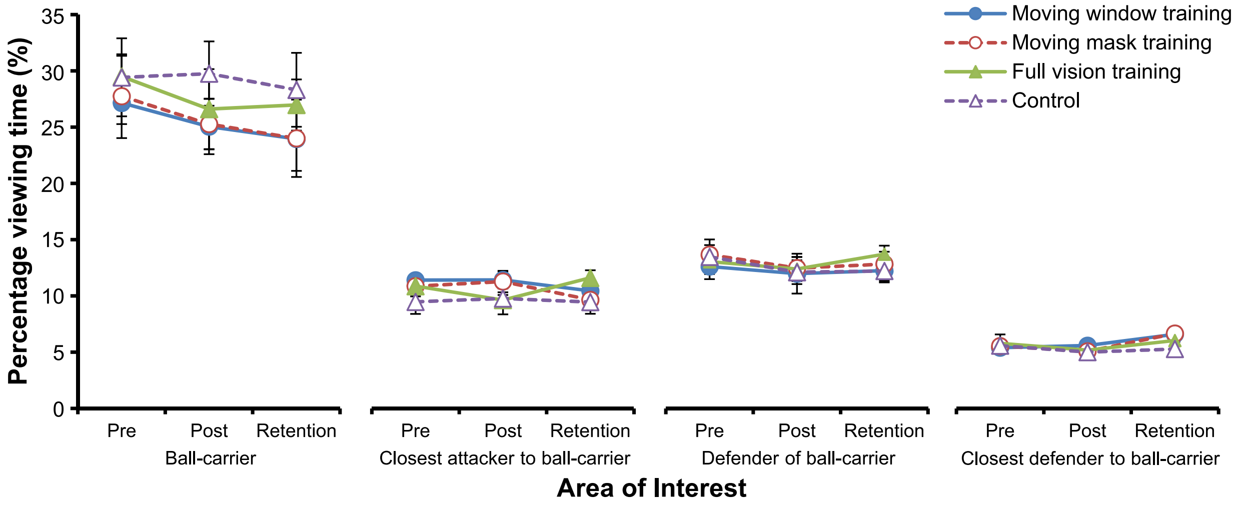
Discussion

In this study, we sought to determine whether decision-making skill in perceptual-cognitive tasks could be enhanced by training that selectively impaired different areas of the visual field. In particular, we were interested in what might prove to be the best form of training to improve the ability to use peripheral vision when performing a dynamic decision-making task. Given the previous finding that the decision-making performance of inexperienced basketball players temporarily improved while peripheral vision was blurred (Ryu et al., 2015), we hypothesized that training with peripheral blur would be effective in improving decision-making skill even when the gaze-contingent manipulation was removed and participants viewed with full (unrestricted) vision or with only the peripheral segment of their visual field. To examine this, novice basketball players were randomly assigned to one of four training groups: a moving-window, a moving-mask, a full-vision, and a control group. The findings revealed that all three training groups increased their decision-making performance immedi-

a. Full vision in test



b. Moving window in test



c. Moving mask in test

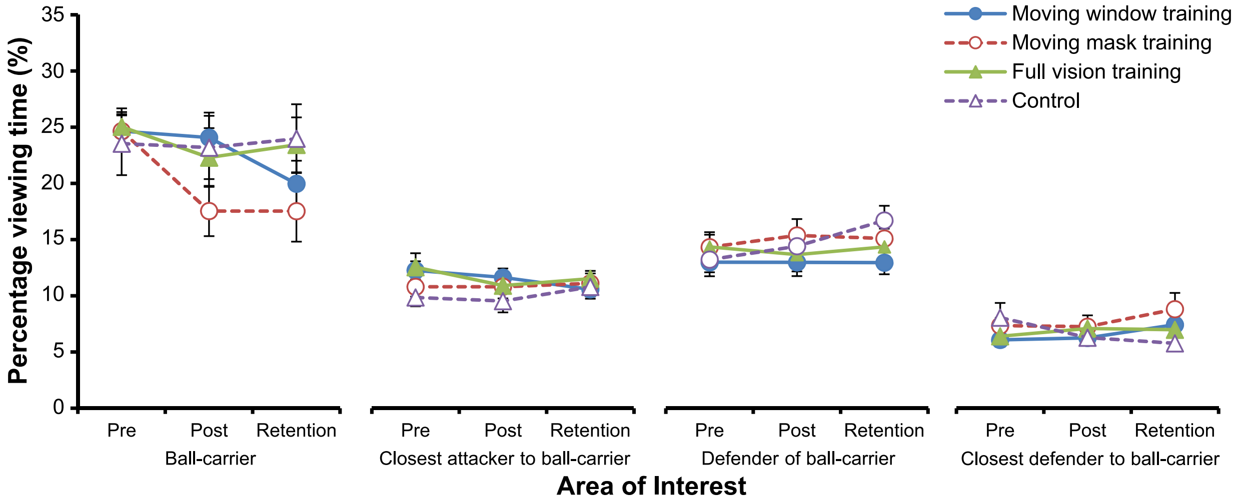


Figure 6. Percentage of total viewing time toward each of four key AoI for the (a) full vision in test, (b) moving window in test, (c) moving mask in test for each group. To reduce complexity, only the four most frequently fixated AoI are shown: the ball carrier and their defender, and the teammate closest to the ball carrier and their defender. Error bars indicate the standard error of the mean.

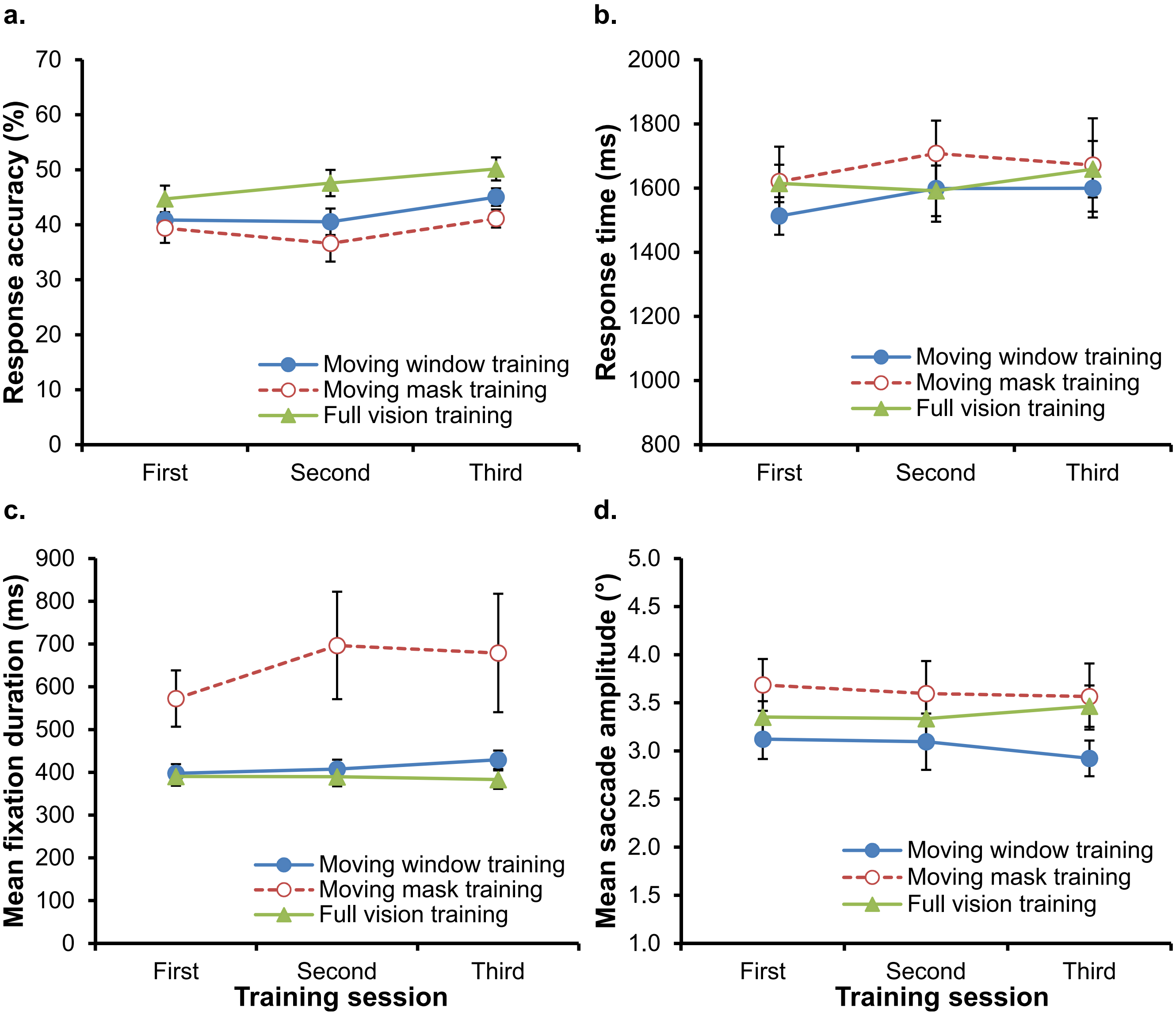


Figure 7. Performance and gaze behavior during training sessions. Figures show changes in (a) RA, (b) RT, (c) fixation duration, and (d) saccadic amplitude for the moving-window training, moving-mask training, and full-vision training groups. Error bars indicate the standard error of the mean.

ately after the training intervention. However, it was the results in the retention test held 2 weeks after the posttest that revealed the decisive differences between the groups. At retention, the decision-making performance of the moving-window training group that trained with blurred peripheral vision was clearly superior to that of the moving-mask training group that trained with blurred central vision. And although the decision-making performance of the moving-window group was not superior at retention to that of the group that trained with full vision, it was only the moving-window training group that benefited from offline gains in performance, that is, continued improvement from posttest to retention test. Despite training when viewing with only clear central vision, the improvements of the moving-window training group from pretest to posttest and from posttest to retention test held irrespective of whether they were tested using central vision, peripheral vision, or the full visual field (i.e., benefits generalized across all viewing conditions). Moreover, their changes in performance were not underpinned by any distinctive alterations to the visual search strategy when compared with the other training groups. Taken together, the findings imply that the performance gains of the moving-window training group were the result of superior information pickup, which generalized across the whole visual field, suggesting that training with blurred peripheral vision improved the ability of less-skilled players to use both their central and peripheral vision.

The advantageous nature of training with peripheral blur

Consistent with other perceptual training studies (Abernethy, Schorer, Jackson, & Hagemann, 2012; Hagemann et al., 2006; Ryu, Kim, et al., 2013), evidence was accrued in this study to demonstrate that repeated practice when viewing decision-making clips is valuable in improving decision-making skill. As Figure 3 (left panel) reveals, all three groups who trained with decision-making scenarios significantly improved their RA from pretest to posttest, whereas the control group, who viewed videos but not of decision-making scenarios, showed no such improvement.

Our a priori prediction, extrapolated from the findings from the Ryu et al. (2015) study, was that following training the *moving-window training* group would demonstrate a greater capability for decision making compared with any of the other training groups. In particular, we expected that moving-window training rather than moving-mask training would lead to improvements in the ability to use peripheral vision when performing the decision-making judgments. The results from the measures of decision-making accuracy collected in this study were largely consistent with these predictions. However, it was the contrast from posttest to retention test that revealed the crucial differences between the three key training groups. The performance of both the *moving-window training* and *full-vision training* groups was better than that for the *control* group in the retention test, and although there was no significant difference between the retention test performance of the *moving-window training* and *full-vision training* groups, it was only the *moving-window training* group who *improved* their performance from posttest to retention test. Although the *moving-mask training* group was able to improve their decision making as a result of the particular type of training they received, their retention test results suggest that any benefits accrued in the posttest were lost 2 weeks later by the time of the retention test. Consistent with our hypothesis, the retention test revealed that moving-window training led to an improvement in decision making when using peripheral vision (in the *moving mask test*) that was not apparent for the *moving-mask training* group. However, it is not clear whether the peripheral restriction applied during moving-window training would lead to long-term benefits in the use of peripheral vision beyond those possible via normal full-vision training.

Are training benefits specific or transferable?

In this study, decision-making performance was tested, on all three occasions, using three different test types: a *full-vision test*, a *moving-window test*, and a *moving-mask test*. The full-vision test provided the criterion condition upon which the true efficacy of the different training interventions was best judged. The other conditions were included to assess the specificity/transferability of training effects. If training benefits are highly specific, improvements in the performance of the *moving-window training* group may be expected to be restricted primarily to the moving-window test (which mirrors the kind of experience accrued by that particular group in training), and for the same reason, improvements in the performance of the *moving-mask training* group may be expected to be restricted primarily to the moving-mask test. Conversely, if training benefits are generalizable and transfer across the different sections of the visual field, then performance improvements for each particular training group might be expected to show on all test types and not just the one that most closely mimics their training experience.

The findings from this study point very strongly to the generalizability of the training benefits accrued by all of the training groups: The training effects were transferable with respect to information pickup from either central and/or peripheral vision. If the moving-window training intervention had instead simply taught participants to attend to information in the central visual field while ignoring peripheral information (without any underlying improvement in information pickup), then posttest and retention test improvements should have been found when viewing with only central vision and with the full visual field but not when viewing with only peripheral vision when the central information available was restricted (rather, performance should have decreased). This was not the case. Instead, the training experienced by the *moving-window training* group provided benefits not just to their ability to use central vision but also their capability to make decisions when information was available across the full visual field and even when information was available to only the peripheral field of view in the moving-mask test. This shows that the attenuation of peripheral information during moving-window training led to better decision-making skill that could subsequently be used across the breadth of the visual field.

Do the different training methods alter gaze in unique ways?

The measures of gaze behavior provide an indication of the visual search strategy used by participants in the different training groups when making decisions. One of the most compelling features of the analyses of gaze in this study was that the type of training experienced (i.e., training group membership) had no measurable impact on any of the gaze parameters that we measured. The different test conditions that were used influenced some elements of gaze, and some measures did change from test to test, but these remained unaffected by whether participants had experienced moving-window training, moving-mask training, full-vision training, or indeed no decision-making training at all.

The impact that the *type of test* had on gaze was largely consistent with the observations described in the Ryu et al. (2015) study (using the same stimuli) and in other studies that have employed gaze-contingent displays (but used other visual stimuli). The participants narrowed their pattern of visual search (with shorter saccades) in the *moving-window test* (for similar findings when viewing static images, see Bertera & Rayner, 2000; Cornelissen, Bruin, & Kooijman, 2005; Loschky & McConkie, 2000, 2002; Nuthmann, 2014) and used a more expansive search strategy (with larger saccades) in the *moving-mask test* (Figure 4; see also Cornelissen et al., 2005; Loschky & McConkie, 2002; Nuthmann, 2014). This indicates that the search strategies were adapted as the participants explored ways to compensate for the restrictions specific to the different areas of the visual field. Fixation durations were higher for all participants in the *moving window in test* and *moving mask in test* (when compared with the *full vision in test*; Figure 5a), consistent with there being an increase in processing time necessary to account for the gaze-contingent display manipulations (Bertera & Rayner, 2000; Loschky & McConkie, 2000, 2002; Nuthmann, 2014). However, again, the crucial finding was that the type of training that participants had undertaken did not moderate any of these effects. The characteristics of the visual search patterns did not differ between groups, even when that training provided extensive exposure to the moving-window or moving-mask manipulations.

What are the underlying mechanism(s) for improved decision making with peripheral blur?

A crucial observation from this study was that there were clear differences in decision making as a result of the type of training experienced, yet there were no associated differences in gaze behavior. If the improvements in decision-making performance seen as a result of training had been attributable to a more efficient pattern of gaze behavior, we would have expected to see clear differences between the groups in the measures of gaze behavior in the posttest and retention test. This was not the case. As a result, this suggests that the improvements in decision-making performance that were observed are likely attributable to a generalized improvement in the ability to pick up task-specific information that could then be applied across the whole of the visual field. Training with peripheral blur may have facilitated this pickup through the guidance of attentional focus toward the critical central cues in the scene. The capacity of inexperienced participants to contemporaneously attend to central and peripheral visual information is most probably limited, and so we propose that the success of the moving-window training is most likely attributable to the attenuation of peripheral demands and distractions. In doing so, the moving-window training encourages attention to be aligned with central vision (although it does not necessarily force the two to be aligned; see Ryu, Abernethy et al., 2013), increasing the likelihood of attention being allocated toward the more informative regions of the visual field (Lingnau, Schwarzbach, & Vorberg, 2010).

It is important to note that the effect of training with peripheral blur in this study was tested on participants who possessed only limited basketball experience, and so the training benefits could be very specific to participants of this skill level. It is likely that the participants in our study possessed only a limited knowledge base to support the pickup of the requisite information required to do well on this basketball-specific decision-making task. The imposition of peripheral blur may have expedited the ability of the less-skilled players to pick up salient information. However, more skilled players who already possess the requisite knowledge may be less likely to benefit from such an intervention. Instead, *moving-mask* training that forces participants to rely on peripheral vision and probably requires observers to apply their existing knowledge base to an area of the visual field that they may be less accustomed to using may well prove to be a more advantageous form of training for skilled players.

One could argue that an alternate explanation for the training effect found in this study is that the peripheral blur could have *enhanced* the pickup of peripheral information. We used blur rather than completely opaque occlusion to obscure selective areas of the visual field in an effort to limit information pickup while still allowing sufficient peripheral information to guide the selection of subsequent fixation location(s) (see also Loschky & McConkie, 2000, 2002; Nuthmann, 2014). However, blur has been found, in some circumstances, to *enhance* the ability of observers to perceive movement (di Lollo & Woods, 1981; Jackson, Abernethy, & Wernhart, 2009; Luria & Newacheck, 1992; Mann, Abernethy, & Farrow, 2010). For instance, Jackson et al. (2009) found that a high level of full-field blur increased the ability of skilled tennis players to anticipate the direction of an opponent's tennis serve. Similarly, Mann et al. (2010) found that full-field blur increased the capability of inexperienced cricket batters to verbally anticipate the direction of cricket balls bowled toward them. It could be argued that, in the present study, the peripheral blur altered the pickup of peripheral information rather than (or possibly in addition to) attenuating attention; for instance, by removing potentially distracting background information to leave only vision of the key information of relative player position. But there are at least two reasons to think that this is unlikely. First, in the studies by Jackson et al. (2009) and Mann et al. (2010), visual blur was applied to the full visual field rather than to one sector of the field. It was reasoned in those studies that the improvements in performance could have been attributable to the attenuation of high spatial frequency information, particularly in central vision. Clearly that is not the case in our study as blur was applied only to the peripheral field (which can resolve only lower spatial frequencies). Benefits in the present study (and in Ryu et al., 2015, experiment 4) have been observed only when the central field was clear and the *periphery* was blurred. In fact, training with central blur was detrimental when compared with the control training performed with normal full vision. A second explanation is that, if peripheral blur were to enhance peripheral information pickup, then one should expect pickup to be possible when viewing with only blurred peripheral information (i.e., with no central vision). This is clearly not the case. In experiment 4 in the study by Ryu et al. (2015), it was found that when viewing with only peripheral vision (i.e., when central vision was fully opaque), the decision-making performance of inexperienced participants was no better than chance, and performance did not improve irrespective of the level of peripheral blur applied. Evidently, the peripheral blur appears unlikely to have aided the pickup of peripheral information in a way that could explain the improved decision-making performance found in this study.

Why were the crucial differences in performance found from posttest to retention test?

The mechanism by which the *moving-window training* group improved from posttest to retention test poses a residual issue for which we see at least two possible explanations. First, it is not completely uncommon to observe offline gains in performance after a period of time without training (e.g., Stickgold, 2005; Telgen, Parvin, & Diedrichsen, 2014; Wright, Rhee, & Vaculin, 2010). These improvements are particularly observed in studies of implicit learning in which skills are acquired using approaches that minimize the concurrent accumulation of verbalizable (declarative) knowledge about how the task is performed. In these studies, it is reasoned that implicit forms of learning are more likely to be resistant to forgetting and as a result engender better skill retention or even skill improvement (e.g., Allen & Reber, 1980). For instance, Abernethy et al. (2012) compared the efficacy of four different methods of perceptual training (viz., explicit learning, verbal cueing, color cueing, and implicit learning) and found that the training group that experienced implicit learning improved their performance in a retention test held *5 months* after the posttest, an improvement that was not achieved by any of the other training groups. Rendell, Masters, Farrow, and Morris (2011) found similar offline gains in the performance of a *motor* task that was learned while experiencing high contextual interference (i.e., in which two or more different skills were learned concurrently and sequenced in a random manner), a form of learning thought to be implicit in nature. But why would a moving window encourage an implicit form of learning whereas a moving mask or full visual field would not? One possible explanation is the way that the gaze-contingent manipulation forced gaze and attention either into or out of alignment. For participants in the *moving-window training* group, the removal of peripheral information ensured that gaze and attention were likely to be aligned. As a result, any conscious reallocation of attention toward the periphery was unnecessary and unlikely to be beneficial. Participants in the *full-vision training* group did have the opportunity to dissociate gaze and attention and in doing so may have required conscious thought to redirect attention peripherally. Finally, participants in the *moving-mask training* group were consistently required to dissociate their attention from their direction of gaze during training. If they wanted to direct attention toward a particular area of the visual field, they were required to target their gaze toward a different area of the visual field. This may have led to a very explicit form of processing, with participants consistently required to think consciously about the direction in which their gaze needed to be directed. Taken together, the degree to which attention and gaze were dissociated is likely to have influenced the level of conscious thought engaged during the training, and as a result, this may have influenced skill retention. Such a hypothesis could be verified by the inclusion of manipulation checks thought to be confirmatory for implicit learning in future experiments (e.g., stress tests, verbal reports of explicit knowledge, or long-term retention tests).

A second potential explanation for the improvement from posttest to retention test is that the posttest itself could have functioned as a recalibration/additional learning opportunity (as it provided 16 clips of full vision with both central and peripheral vision available) but that this opportunity was able to be used only by those training groups that had already acquired the requisite ability to use central vision. For the *full-vision* *training* group (who have trained with full vision throughout), the availability of some further trials with full vision in the posttest probably did not assist them (the test experience provided nothing new), and therefore, their performance did not change from posttest to retention test. For the *moving-window training* group, the training condition likely facilitated greater focal attention toward central cues. This underpins improvement from the pretest to the posttest; however, there was no opportunity to calibrate the improved central pickup with concurrent (clear) peripheral information. The availability of some full-vision trials in the posttest may have provided an opportunity to do so, and this could then explain the improvement from posttest to retention test. For the *moving-mask training* group, the training condition provided no stimulus or opportunity for central vision learning. Consequently, for that particular training group, there might not have been the primed base to benefit from the availability of the full-vision trials in the posttest in a way that was comparable with that enjoyed by the *moving-window training* group. The inclusion of full-vision trials into a moving-window training program would help to establish whether this possible explanation holds true.

Future challenges

The somewhat counterintuitive nature of the findings from this study poses new and interesting questions for those who seek to understand and/or train perceptual-cognitive skill in dynamic tasks. The first relates to the optimal design of gaze-contingent perceptual-training interventions. In our study, the intervention period was relatively short (three sessions of ~25 min), and it is likely that participants had not maximized their possible learning benefits by the end of the intervention (Figure 7a). Therefore, our results may not fully reflect the complete extent of the benefit of moving-window training. Empirical work that uses longer intervention periods is required to verify this claim. As discussed in the previous section, the mechanism underlying the continued improvement of the moving-window group from posttest to retention test also warrants exploration.

From a more practical standpoint, it is imperative to test whether perceptual skill gains off court transfer to improved decision making in competition. Successful on-field transfer has been demonstrated in perceptual-training studies designed to enhance *anticipatory skill* in less-skilled (Farrow & Abernethy, 2002; Williams, Ward, Knowles, & Smeeton, 2002) and highly skilled athletes (Hopwood, Mann, Farrow, & Nielsen, 2011), but it remains unclear to what degree video-based decision-making training might improve on-field performance. One limiting factor is that perceptual-training studies necessarily rely on highly representative and structured scenarios that ensure there is an agreed best response to unambiguously measure decision-making proficiency. Yet scenarios in matches are not always so highly structured, and the correct decision is not always so clear-cut. It remains unclear whether the improvements evidenced in our study are restricted to structured scenarios or would generalize to situations in which the decision about who to pass the ball to (and when) might not be so obvious. Practical matters of this kind can be examined in more ecologically valid simulations in which the player must couple an action to a decision (e.g., Bruce, Farrow, Raynor, & Mann, 2012) and/or by the analysis of match statistics designed to evaluate the success of decisions made in real matches (e.g., Bruce, Farrow, Raynor, & May, 2009).

Conclusions

This study used the gaze-contingent paradigm in an attempt to determine whether perceptual training when viewing with the selective impairment of different areas of the visual field would lead to a superior means of training perceptual skill. The findings highlight that training with a moving window of clear central vision and blurred peripheral vision provides a promising means of training decision-making skill in dynamic externally paced activities and, in particular, in improving the ability to use peripheral vision when performing these tasks. The moving-window training group demonstrated advantages in information extraction that held irrespective of test type, indicating that the training effects were generalizable to when viewing with full unrestricted vision and not just restricted to when viewing with a moving window. As a result, this approach appears to offer a useful means of modifying information pickup in a manner that is beneficial for decision making. These results suggest that, at least for task novices, there are benefits in adopting training approaches that force attention and gaze into alignment to help effectively enhance decision-making skill.

Keywords: perceptual training, decision making, gaze-contingent display, attentional control, central vision, peripheral vision

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Footnotes

[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 and is taken as our working definition throughout this article.

[2] Similarly, one might expect stress and/or arousal to alter the *perceptual span*, a measure of the breadth of information that can be extracted within a single fixation. Experts in static tasks such as chess are known to have a larger perceptual span than lesser-skilled performers do (Reingold, Charness, Pomplun, & Stampe, 2001); however, it is less clear whether the perceptual span is related to expertise in *dynamic* tasks such as those experienced in sports (Cañal-Bruland, Lotz, Hagemann, Schorer, & Strauss, 2011).

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