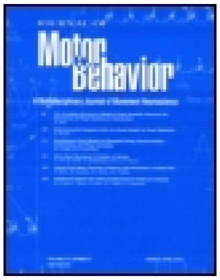

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RESEARCH ARTICLE

Visual Search Differs But Not Reaction Time When Intercepting a 3D Versus 2D Videoed Opponent

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ABSTRACT. The authors aimed to identify differences in (a) visual search and (b) reaction time when athletes sidestepped to intercept 2D versus 3D videoed opponents. They hypothesized that participants would (a) fixate on different parts of the opponent's body and (b) react quicker when responding to the 3D versus 2D opponent due to the added depth cues. A customized integrated stereoscopic system projected the video stimuli and synchronously recorded the gaze and motor behaviors of 10 men when they responded to two- (2D) and three-dimensional (3D) opponents. The number and duration of gaze fixations were coded according to locations on the opponent's body (head, shoulders, arms, trunk, pelvis, legs) or otherwise (other). Mediolateral pelvic movement was used to infer reaction time. Participants spent 16% less time fixating on the trunk and 23% more time outside the 3D opponent's body compared with the 2D stimulus. No reaction time differences were found. Although participants fixated less on the 3D opponent's body and, by inference, invested less perceptual processing toward interpreting the opponent's movements compared with the 2D condition, they performed the interception task equally fast in both conditions. Three-dimensional depth cues may provide more meaningful information per fixation for successful task performance.

Keywords: 2D versus 3D visual stimuli, perception-action coupling, perceptual-motor skill, sidestep

To deliver skilled action, humans must prospectively perceive what the environment affords and exercise appropriate motor control (Watson et al., 2011). This combined ability to perceive affordances (opportunities to act) within an environment (Gibson, 1979) and act appropriately is referred to as visual-perceptual-motor skill (Jackson & Farrow, 2005). During the course of skilled action, visual perception is tightly constrained by an individual's previous motor actions, which in turn are affected by perception (Williams, Davids, Burwitz, & Williams, 1994). This depicts the perception-action cycle, which links visual information perceived in the environment to physical behaviors over the time course of skilled action (Newell & McDonald, 1994). Although visual-perceptual-motor skills are evident in the performance of simple everyday tasks (i.e., reaching and grasping; Goodale, Westwood, & Milner, 2004), it is invasion team sports (i.e., hockey) that provide ideal environments for studying the visual-perceptual-motor relationship. Invasion sports require athletes to adapt their perception-action cycles in response to the ever changing demands imposed by the game environment, without compromising team strategies or match rules.

Despite the ideal environment that invasion sports provide for investigating visual-perceptual-motor expertise, the bulk of previous research has focused solely on visual-perceptual (i.e., anticipation and pattern recognition; Abernethy, 1990; Abernethy & Russell, 1984, 1987; Goulet, Bard, & Fleury, 1989) or motor skill in isolation (Draper & Lancaster, 1985). Efficient sport performance is rarely the result of enhanced visual-perceptual ability or motor skill in isolation, but a combination of both components functioning as an interdependent couple in the sport-specific environment (Williams, Davids, & Williams, 1999). The research bias toward independent examination of visual-perceptual or motor skill can be attributed to two main difficulties: (a) the difficulty of simulating the visual-perceptual demands of a game environment in laboratory settings and (b) the challenging task of measuring visual-perceptual skill and motor skill synchronously (Williams et al., 1994).

To overcome the first aforementioned difficulty, previous research has attempted to improve the game realism of laboratory environments via the use of two-dimensional (2D) video projections of sport-specific situations to prompt and examine skilled action. In netball, for example, one study found no difference in planned agility runs between experts and novices, although a reactive agility test was able to discriminate skill level due to the inclusion of a sport-specific visual stimulus (Farrow, Young, & Bruce, 2005). However, human vision is three-dimensional (3D) and depth perception is often critical to successful performance in various sports (Vickers, 2007). The use of 2D projections may elicit visual-perceptual-motor responses that do not fully reflect those observed in game situations. As such, this research group recently developed a 3D stereoscopic system for use in a laboratory setting that is capable of projecting sport-specific scenarios with realistic scale and depth (Lee, Bourke, Alderson, Lloyd, & Lay, 2010). Despite the stereoscopic system's potential advantage over other displays in creating a more game-realistic visual experience, it is not known if visual-perceptual-motor responses to the same stimuli, projected in 2D and 3D conditions are different. As such, an important addition to the system's capabilities as a research tool is to allow the synchronous measurements of visual-perception and action within a quasi game-realistic environment (Williams, Davids, Burwitz, & Williams, 1992).

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The vision-in-action system developed by Vickers (1996) permits the synchronous measurement of visual-perceptual and motor skills of an athlete in a sport specific environment. With the use of a gaze tracker, visual-perceptual skill is inferred from gaze fixations; "gaze held on an object or location of interest for a minimum of 100 milliseconds (ms) and within three degrees of visual angle, allowing conscious information processing" (Carl & Gellman, 1987). The relevant motor skill is synchronously recorded in time using 2D video cameras and selected kinematic variables are assessed following the testing session. Although skilled action is assessed based on coupled visual-perceptual and motor skill measurements, much of the work that resulted from the use of this system has focused on closed skills (e.g., putting in golf; Vickers, 1996) which are less demanding of visual-perceptual skill. Further, each frame of vision-in-action data is 2D and sampled at 30 Hz, limiting the amount of objective motor skill data that can be obtained. Human motion is of course 3D and common sporting maneuvers such as running and sidestepping, have traditionally been sampled at the higher frequencies of 100–250 Hz (Cochrane et al., 2010; Lee, Reid, Elliott, & Lloyd, 2009). Over the past decade, laboratory-based 3D motion analysis systems (e.g., Vicon-ViconPeak Ltd., Oxford, England) have been established as the gold standard for movement quantification. Consequently, the integration of the stereoscopic system with 3D motion analysis and gaze tracking systems not only allows for a wider range of coupled visual-perceptual-motor skills to be examined in a quasi game-realistic environment, but also enables 3D quantification of the relevant motor skill.

In the present study we examined whether the visual-perceptual-motor responses of participants differed between the 2D and 3D game-based scenarios. To allow for this comparison, a customized 3D stereoscopic system (Lee et al., 2010) was integrated with a Vicon motion analysis system and a modified Mobile Eye gaze tracker (ME; Applied Science Laboratories, Waltham, MA). This integrated stereoscopic system facilitates controlled and repeatable investigations of visual-perceptual-motor skills, while incorporating a higher degree of realism than currently exists in this field of research. The first aim of this study was to compare and identify any differences in gaze behavior of athletes when sidestepping from a standing start to intercept a 2D versus 3D videoed opponent that was projected using the integrated stereoscopic system. We hypothesized that there would be differences in gaze fixation quantity and duration in total, and on different body parts of the 3D compared with 2D virtual opponent. This hypothesis was based on previous research reporting different visual search behaviors when watching 3D stereoscopic compared with 2D monoscopic movies (Hakkinen, Kawai, Takatalo, Mitsuya, & Nyman, 2010). The second aim was to identify differences in reaction time when athletes initiated the interceptive sidestep. We hypothesized that the players would react faster when sidestepping in the 3D scenario versus the 2D scenario. This hypothesis was based on the suggestion that human vision is three-dimensional and depth perception is often critical to successful performance in various sports. Answers to the hypotheses may provide insight into whether a more realistic 3D visual-perceptual environment affects a performer's gaze behavior and thereby affords a different amount of time to react when perceiving the same stimuli in 2D.

Method

Participants performed a left or right sidestep from a standing position, to simulate the interception of an oncoming opponent projected in 2D and 3D by the integrated stereoscopic system who changed directions bilaterally. The time required by participants to initiate an interception of the opponent (motor skill), and the quantity, duration, and locations of the participants' gaze fixations on the projections (visual-perceptual skill), were also recorded using the integrated system during the performance of the defensive interception task.

Development of the Integrated Stereoscopic System

The integrated stereoscopic system presents the game-based visual stimulus in 2D and 3D conditions, and records the coupled visual-perceptual-motor responses of participants performing the interception task via its components parts. These parts comprise of the previously developed stereoscopic system (Lee et al., 2010), a Vicon motion analysis system, and an ME. To obtain the appropriate experimental data, the ME needed to be modified and all the component parts had to be integrated.

The 3D stereoscopic system used to project the videoed opponents in 2D and 3D conditions was developed using specialized techniques described previously (Lee et al., 2010). For this study, the 3D and 2D projected scenarios depicted an initially stationary offensive opponent, who converged in a straight line toward the laboratory-based participant and sidestepped either to the left or right of the participant. Filming of the 3D and 2D scenarios was performed in the laboratory where the experiment was conducted to maintain visual field consistency. With the exception of the converging virtual opponent, all objects in the laboratory that were filmed and projected on the screen remained stationary during testing. This arrangement maintained ecological reality and prevented the participants from getting distracted when reading the opponent's movements.

During filming, two high-definition video cameras were mounted on a customized dual-mount rig and separated by 6.5 cm, the interocular distance of an average person (Wallach, Moore, & Davidson, 1963). This setup allowed the recording geometry of the cameras' optics to be matched with the viewing geometry of the participants (Lee et al., 2010). Such an approach ensured that the filmed and projected 3D scenarios were accurate in scale and depth, and when viewed by participants recreated a visual experience similar to viewing a real-life opponent converging and sidestepping in the laboratory. Twenty-four clips consisting of 12 clips featuring the projected opponent in the respective 2D and 3D conditions were created. An equal number of clips ($n = 6$) featured the opponent sidestepping to either the left or right of the laboratory-based participant in each condition.

The video clips chosen for use as visual stimuli for the defensive interception task had to meet specific inclusion criteria. The approach velocity of the opponent had to be 4.0 ± 0.2 ms^{-1} as it represented recorded speeds of athletes sidestepping in game situations (Cochrane, Lloyd, Buttfield, Seward, & McGivern, 2007). The opponent was also required to sidestep at approximately 4.6 m from the recording cameras. This distance ensured that the opponent's body was not occluded by the boundaries of the screen and remained fully visible to the participant at the commencement of the maneuver.

During postprocessing, each clip was cropped to 6 s in length from start to end and key events were temporally matched. For example, the opponent remained stationary for two seconds at the start of each clip before run commencement. The start of the run was defined as the first observable movement in the opponent's leading leg while pushing off, which was ascertained via visual inspection of the footage. After approximately 3.7 ± 0.1 s, the projected opponent performed the offensive sidestep. Commencement of the sidestep was indicated by the first observable lateral movement of the foot segment from the pelvic midline. The end point of the video clip corresponded to the first frame that the opponent moved beyond the boundaries of the screen after sidestepping. These temporal events were coded by inspecting frame-by-frame footage using Final Cut Pro 6 (Apple Inc.) video editing software. The 3D and 2D projections were created using the same video recordings. The 2D clips were created using footage captured solely from the right video camera while the 3D clips were created using footage from both cameras. Viewed without wearing polarized lenses, the 3D projection would look blurred due to image separation.

The sidestep of the laboratory-based participant was captured using a 12-camera Vicon motion analysis system sampling at 250 Hz, which follows the protocol of the majority of previous sidestepping studies performed in our laboratory (Cochrane et al., 2010; Dempsey, Lloyd, Elliott, Steele, & Munro, 2009; Dempsey et al., 2007; Donnelly et al., 2012). Specifically, the system was used to track the lateral displacement of the participants' center of pelvis during the interception task. The pelvis was defined by four retroreflective markers located on the left and right anteroposterior superior iliac spines. The center of the pelvis was derived from the average 3D positions of these four markers.

Gaze fixations were measured at 30 Hz using the ME. The ME is a tetherless video-based monocular system, which consists of a spectacle mounted unit and a rear mounted unit. There are two cameras mounted on the spectacle unit: (a) an eye camera that records an individual's point of gaze solely from the right eye, via the displacement of the pupil in relation to the cornea during vision; and (b) a scene camera that captures the visual field in the frontal plane. The point of gaze determined from the eye camera is superimposed as a crosshair on the footage recorded by the scene camera allowing the determination of fixation locations. The combination of footage captured from the eye camera and the scene camera is recorded to tape via the rear mounted unit.

The original spectacle unit of the ME did not support stereoscopic viewing. In addition, due to two offset images arising from image separation between the left and right projected image, point of gaze could not be clearly established on the stereoscopic footage captured by the scene camera. To enable stereoscopic viewing through the ME spectacle unit, linear polarized lenses (Berezin Stereo Photography Products, Abedul, CA) were attached to the outside of the original lenses (Figure 1). The polarized lenses for the left and right eyes were aligned at right angles to each other, matching the angle of the polarized light from each projector (Lee et al., 2010). This arrangement resulted in binocular disparity, such

FIGURE 1. The original and modified versions of the Mobile Eye gaze tracker. (Color figure available online).

that each eye only observed the corresponding left or right projected footage. The brain fuses these images as one, resulting in depth perception. To overcome the problem of two offset images being recorded by the scene camera, a polarizing filter that matched the angle of polarized light from the projected footage intended for the right eye was overlaid on the lens of the scene camera. The choice to attach a filter that occluded the left projected footage, while allowing the right projected images to be captured by the scene camera, ensured that the superimposition of the point of gaze crosshair was standardized to the right eye only, being the only eye tracked by the ME system.

The component parts of the integrated stereoscopic system were synchronized using infrared timing gates and a custom-built interface unit. The infrared timing gates consisted of a transmitter and a receiver. The transmitter emitted infrared light, which was reflected by the receiver, forming a continuous beam of light. When the beam of infrared light was occluded (i.e., by a person travelling through the gates), a square impulse was generated in the analogue signal. The generated impulse was used to trigger the projection of the filmed 2D and 3D scenarios, and also to temporally synchronize the data recorded from the individual component systems.

To use the generated impulse for the aforementioned purposes, an interface unit was developed to receive and convert the impulse into a format that could be interpreted by nonspecialized software. The interface unit functioned similar to a standard universal serial bus interface keyboard. Depending on which port on the interface unit the timing gates were connected to, once an impulse was received from the gates, a selected alphabetical character was generated. The generated character triggered the delivery of the 2D and 3D videos. The interface unit also contained ports that output and relayed the impulse to selected analogue channels on the host system's analogue to digital converter board. In the present study, the host system was the Vicon motion analysis system. The impulse generated from the gates was coregistered as a square wave signal in the Vicon system's analogue channel inputs, allowing for the temporal synchronization of the video footage, the recorded 3D motion data, and the gaze behavior data.

Following complete development of the integrated stereoscopic system, it was tested for temporal robustness. Latency tests were performed to ascertain the delay between the impulse that was generated from occluding the light beam of the timing gates, to the full presentation of the first frame of stimuli footage on the screen. A consistent delay of 110 $\pm$ 5 ms was measured. This delay was incorporated at the post-processing stage of the data collected using the Vicon system in the assessment of the time to initiate an interception.

Participants

Ten active men (M age = 22.1 $\pm$ 1.3 years, M height = 180 $\pm$ 10 cm, M mass = 76.7 $\pm$ 11.2 kg) who participated in various sports (three in Australian Rules football, two in basketball, two in volleyball, two in tennis, and 1 in rugby union) and were competent in performing side-to-side movements in response to visual stimuli (e.g., ball or opponent) voluntarily participated in this study. Ethical clearance for the project was obtained from the Human Research and Ethics Committee at the University of Western Australia. All participants provided written informed consent prior to their involvement in the research.

Experimental Procedures

Prior to experimental data collection, specific calibrations were performed to the testing system. A dynamic calibration to establish the reconstruction volume, followed by a static calibration to define the global origin (0,0,0) of the laboratory was performed for the Vicon motion analysis system. The participant was then fitted with the ME system's spectacle and data collection units and positioned in front of the stereoscopic screen at the exact location where the interception task was to be performed. While keeping the head as still as possible, participants were required to locate nine calibration points within the perimeter of the 2.67 $\times$ 2.0 m (4:3 aspect ratio) display screen. To track lateral displacement of the center of pelvis during testing, four retro-reflective markers located on the left and right anteroposterior superior iliac spines were attached to the participants' pelvis in accordance to the UWA Lower Body and Torso model (Figures 2A and 2B; Besier, Sturnieks, Alderson, & Lloyd, 2003; Dempsey et al., 2009; Dempsey et al., 2007; Lee et al., 2009).

Following calibration, participants completed a familiarization period involving exposure to the 2D and 3D

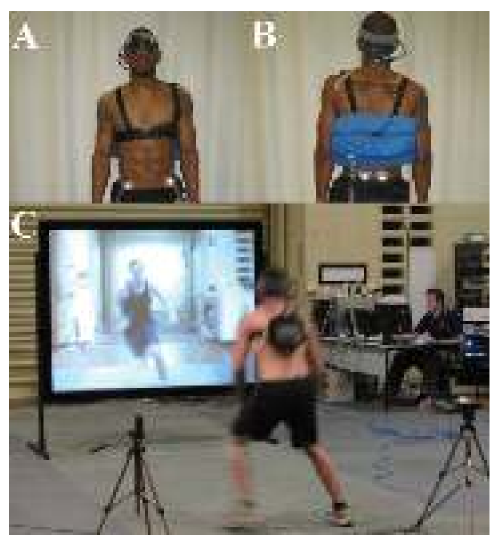

FIGURE 2. Front (**A**) and back (**B**) view of the participant with the retroreflective markers attached to the pelvis and wearing the Mobile Eye gaze tracker prior to performing the sidestepping interception task (**C**). (Color figure available online).

projections of the oncoming opponent, changing directions to the left or right. The bilateral sidestepping defensive interception movements were then introduced. After familiarization, data collection commenced, which required participants to perform eight defensive interception trials; four left and four right, in the 2D and 3D conditions. All trials were presented randomly.

The Vicon and ME commenced recording of experimental data while the participant was in a standing static pose and prior to onset of the projections (Figure 3). The participants triggered the presentation of the 2D and 3D stimuli footage by stepping through the timing gates (Figure 3). After stepping through the gates which were positioned at 4.65 m from the screen, participants were instructed to remain as stationary as possible in preparation for the interception of the projected oncoming opponent. Following determination of the opponent's direction of travel, participants were required to simulate an interception as quickly as possible by sidestepping into the direction of travel of the simulation (Figure 2C). The 2D and 3D projections of the opponent sidestepping either left or right were block-presented and counter-balanced between participants. Within a 2D or 3D block, the projected opponent sidestepping either to the left or right was presented randomly. Participants completed a total of 24 trials, with 12 trials (six interceptive sidesteps performed to the left and right respectively) completed in the 2D and 3D conditions, respectively.

The gaze behavior variables selected were widely investigated in the research domain of visual search and perceptual skills (Vickers, 2007; Williams et al., 1992; Williams et al., 1994; Williams et al., 1999), and were measured from the onset of the footage to initiation of the projected opponent's sidestep (Figure 3). In the respective 2D and 3D conditions, the total number of gaze fixations and duration of these fixations were averaged across 12 trials for each participant. Additionally, the total number of fixations and duration of these fixations normalized to 100% for each participant were coded according to 11 fixation regions, which covered the visualization both on and off the body of the videoed opponent (Figure 4). Nine regions were categorized on the opponent's body (head, left shoulder, right shoulder, left arm, right arm, trunk, pelvis, left leg, right leg). These regions covered every segment of the opponent's body to provide an indication of the bodily cues used by participants to decide their sidestep direction for the interception task. Selection of these fixation regions was guided by a prior information gathering session that was performed informally. Players from a semiprofessional soccer team indicated that the selected segments were visual cues they would potentially use to judge where an opponent was moving in a game situation. Missing data from blinking were coded as occluded while fixations on the screen but off the opponent's body were coded as others. Differences in the average number of fixations and duration of fixations in all locations were ascertained between the 2D and 3D conditions.

In the respective 2D and 3D conditions, 3D motion data measured during the interception task were averaged across 12 trials. The time taken to initiate an interception was calculated from the onset of the projected opponent's sidestep, to the first measurable lateral shift of the participant's center of pelvis in the mediolateral plane (Figure 3). The movement variable, initiation of pelvic movement, was selected because pelvic control is essential in preserving body stability and the development of final posture during locomotion (Slocum & Bowerman, 1962) and body reorientation (Brault, Bideau, Craig, & Kulpa, 2010). When the participant was stationary, the mean position of the center of pelvis was calculated over a 1-s period from the motion data. Due to baseline pelvic movement, the onset of a lateral pelvic shift in the direction of the interception was only considered for analysis when the position of the center of pelvis was greater than five standard deviations from the mean. Differences in the time to initiate an interception were ascertained between the 2D and 3D conditions.

Statistical Analysis

The first hypothesis was tested by analyzing the differences in the average number of fixations and duration of fixations in all locations, between the 2D and 3D conditions,

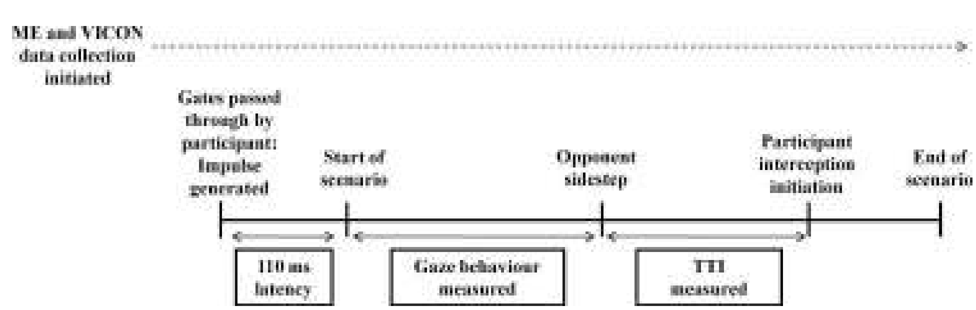

FIGURE 3. Time continuum illustrating periods of gaze behavior and time to initiate interception (TTI) data collection, relative to the presentation of visual stimulus. ME = Mobile Eye.

TABLE 1. Total Number of Fixations and Fixation Duration Averaged Across 12 Trials and Participants in the 2D and 3D Conditions

	2D	3D
Number of fixations	6.2 ± 1.1	6.5 ± 1.3
Fixation duration (ms)	332.7 ± 156.6	294.0 ± 119.6

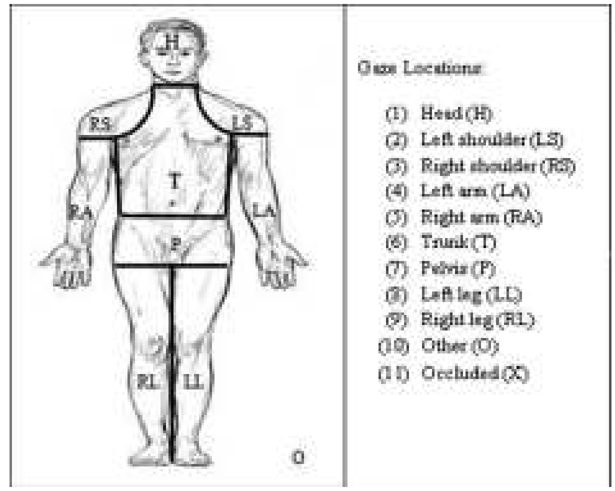

FIGURE 4. Regions of interest for coding gaze fixations.

using separate one-way repeated measures analysis of variance (ANOVA). The differences in the total number of fixations and percentage of time fixating on various regions between conditions were analyzed using separate two-way (Location × Fixation Duration) repeated measures ANOVA with an alpha level of <.05. Significant interaction effects were followed up using two-tailed paired *t* tests.

The second hypothesis was tested by analyzing the differences in the time to initiate an interception on the 2D projected opponent compared with the 3D stimulus using two-tailed paired *t* tests with an alpha level of <.05.

Results

With respect to our first hypothesis, we found no significant differences in the total number of fixations, $F(1, 9) = 0.694$, $p = .087$, and the duration of fixations, $F(1, 9) = 1.723$, $p = .222$, that was averaged across trials and participants, between the 2D and 3D conditions (Table 1). However, a significant interaction effect was observed between the 2D and 3D conditions for the total number of fixations, $F(10, 90) = 2.34$, $p = .047$, and normalized fixation duration, $F(10, 90) = 6.766$, $p = .004$, averaged across participants on regions of interest. Post hoc paired *t* tests revealed a significant increase in the number of fixations, $t(9) = 3.645$, $p = .005$, and percentage of time fixating on other regions, $t(9) = 3.705$, $p = .005$, and a significant decrease on the trunk, $t(9) = –2.890$, $p = .018$; $t(9) = –2.686$, $p = .025$, in the 3D condition (Table 2). The time spent fixating on all other regions exhibited no significant differences between the 2D and 3D conditions.

With respect to our second hypothesis, we found no difference in the average time required to initiate an interception of the opponent between viewing conditions, $t(9) = 0.465$, $p = .652$ (Figure 5).

TABLE 2. Total Number of Fixations and Fixation Duration Normalized to 100% Averaged Across Participants and Coded According to 11 Fixation Regions on the Projected Opponent's Body

	Total number of fixations		Total fixation duration (%)	
Location	2D	3D	2D	3D
H	11.9 ± 11.5	9.3 ± 12.1	14.0 ± 15.3	10.7 ± 15.4
LS	8.3 ± 7.5	4.9 ± 8.4	9.1 ± 9.0	6.6 ± 11.5
RS	5.5 ± 7.8	5.2 ± 6.1	5.2 ± 7.5	6.1 ± 7.5
LA	1.7 ± 1.8	2.3 ± 5.2	1.6 ± 2.1	1.8 ± 4.1
RA	1.4 ± 1.5	2.7 ± 5.0	1.4 ± 1.6	2.2 ± 4.4
T	16.7 ± 10.0*	8.6 ± 7.8*	26.7 ± 20.6*	11.3 ± 11.7*
P	6.2 ± 8.3	5.6 ± 8.3	12.8 ± 18.8	9.6 ± 17.0
LL	4.5 ± 8.3	5.6 ± 8.9	5.2 ± 10.1	6.3 ± 10.7
RL	1.7 ± 2.5	2.2 ± 3.2	1.5 ± 1.9	2.1 ± 3.2
O	15.2 ± 11.8**	30.6 ± 15.7**	20.8 ± 20.6**	42.1 ± 26.4**
X	0.7 ± 1.6	0.6 ± 1.3	1.8 ± 4.6	1.1 ± 2.5

Note. Regions include head (H), left shoulder (LS), right shoulder (RS), left arm (LA), right arm (RA), trunk (T), pelvis (P), left leg (LL), right leg (RL), occluded (X), and other (O).
*$p < .05$. **$p < .01$.

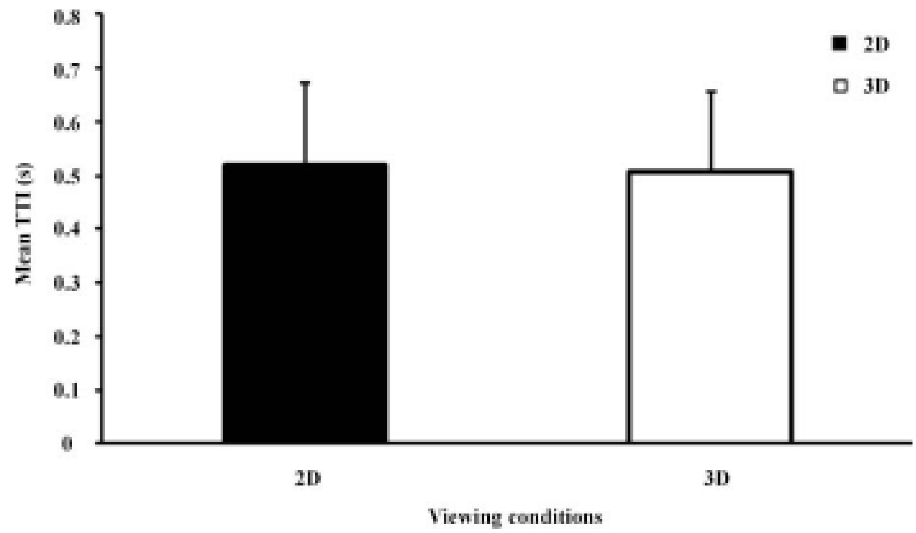

FIGURE 5. Average time to initiate an interception of the projected opponent in 2D and 3D. Error bars represent the mean standard deviation across participants and trials.

Discussion

The purpose of this study was to determine whether the 2D versus 3D videoed opponent that was projected using our customized integrated stereoscopic system afforded different visual search behavior and motor response times when participants sidestepped to intercept the opponent. Participants fixated less and for shorter periods on the trunk of the projected opponent in the 3D condition and more outside of the opponent's body (other) compared with the 2D condition, partially supporting our first hypothesis. No differences were found in the absolute total number and duration of fixations. Additionally, no differences were found in the time to initiate an interception of the opponent in both the 2D and 3D conditions. This finding does not support our second hypothesis and suggests that there was no difference in the perception of affordances between the conditions.

Differences existed when gaze fixations were broken down according to regions on and off the opponent's body in the 3D and 2D conditions. Participants fixated less and for shorter durations on the trunk of the projected 3D opponent compared with the 2D condition. A corresponding increase in the number of fixations and time spent fixating on regions outside the body of the opponent was also observed in the 3D condition. This fixation shift from the body of the projected 2D opponent to nonsubject areas of the 3D display may be due to distraction arising from more spotlights of attention (Cave & Bichot, 1999). That is, objects in the visual field, which drew little attention when viewed in mono, may draw more attention when viewed in stereo due to increased depth cues. This corroborates the recent work of Hakkinen et al. (2010), who reported more scattered visual fixations when participants watched a stereoscopic movie, compared with more focused visual fixations on objects of interest when the same movie was viewed in mono.

The visual fixation shift from the trunk of the projected 3D opponent to other regions of the display may also be explained by distraction caused by the looming sensation imposed by the converging opponent (Eysenck, 1992). Converging stereoscopic images may enhance a viewer's sense of presence, which is defined as the subjective experience of being physically located in a computer generated environment rather than the location of the computer itself (Freeman, Avons, Pearson, & Ijsselsteijn, 1999; Hendrix & Barfield, 1996; Ijsselsteijn, Ridder, Hamberg, Bouwhuis, & Freeman, 1998). Increased presence may translate to increased arousal and/or anxiety (Eysenck, 1992), resulting in the individual becoming more susceptible to peripheral distractions as indicated by increased visual fixations away from objects of interest (Ripoll, 1991; Williams & Elliot, 1999). These suggestions remain speculative as no measures of arousal, anxiety, or presence were administered.

The finding of no between condition differences in the total number and duration of fixations may be explained by the simplicity of the visual-perceptual-motor task. An increased sense of presence or immersion educed by 3D compared with 2D displays has been suggested to facilitate the performance of tasks that observers are unfamiliar with and are still in the process of mastering (Welch, 1999). Keeping this in mind, the task of standing stationary and responding to a sole opponent could have been easily mastered by the participants after just limited exposure. Consequently, participants may have been able to obtain sufficient information for successful task performance from the 2D image alone, without utilizing the added depth information provided by the 3D display via increased fixations. Conversely, the depth cues unique to the 3D display could have contributed toward task performance but were processed using peripheral vision instead of central vision. These pertinent cues, although not presented as visual search behavior that can be quantified using a gaze tracker, could facilitate anticipatory responses via enhanced cognitive interpretations (Abernethy & Russell, 1987).

The similar times to respond to the opponent coupled with the minimal differences found in visual search behavior between the 2D and 3D conditions seem to suggest that there is no advantage afforded when utilizing 3D visual stimuli over 2D displays for the performance of visual-perceptual-motor tasks. Closer inspection of the data would suggest otherwise. Participants fixated less on the 3D opponent's body and by inference, invested less perceptual processing toward interpreting the opponent's movements compared with the 2D condition. Yet, they still obtained sufficient information to perform the interception task within the same timeframe in both conditions. The added depth component in the 3D footage could have resulted in each fixation acquiring more useful cuing information for task performance and thereby afforded participants earlier reading of the opponent's movements. Why then did the participants not react faster in the 3D condition compared with the 2D scenario? There may be an optimal time-to-contact when performing defensive interception tasks. Even though participants in the 3D scenario were able to perceive the opponent's direction of travel earlier, they could have waited until the optimum moment to move in order to achieve the goal of the task. If the task was evasive in nature rather than interceptive, any advantage afforded by the 3D depth cues might have become apparent and is an important consideration for future work.

A limitation of the present study, which may explain the lack of differences in visual-perceptual-motor responses between the 2D and 3D conditions, relates to the simplicity of the visual scenario presented and motor task required. Using an object discrimination task, Atchley and Kramer (1997) reported that attentional focus and reaction time were only influenced by depth, when two or more distracters were presented at different depths and in proximity to the computer-generated objects of interest. Though contextually different, these findings suggest that the visual-perceptual load in any given scenario has a pivotal effect on how depth cues are utilized for attentional focus. Considering that a shift in attention may precede a shift in gaze (Deubel & Schneider, 1996; Henderson, 2003; Kowler, Anderson, Dosher, & Blaser, 1995), it may be hypothesized that increasing the attentional demands of the task (i.e., by projecting multiple opponents at different depths in the 3D scenario) may have produced more pronounced 2D versus 3D differences in the present study.

Future researchers investigating visual-perceptual-motor skill using the integrated stereoscopic system should consider systematically increasing the visual-perceptual loads of the visual stimulus (e.g., increasing number of opponents in the scenario from one to three) and the motor-task complexity (e.g., performing a running evasion as opposed to an interception from a standing stationary position). Such an approach may have elicited more visual-perceptual-motor skill differences between the 3D and 2D conditions. Vaeyens, Lenoir, Williams, Mazyn, and Philippaerts (2007) reported that the visual search rate of soccer players increased, and the quality of decision making between experts and novices were magnified, when players had to view footage of increasingly complex game situations (e.g., increasing the number of offensive to defensive players) and decide on appropriate actions. Furthermore, increasing the complexity of the motor task, such as running and evading a videoed opponent rather than intercepting an opponent from a stationary position, could potentially yield more differences in visual-perceptual-motor responses. With running and evading an opponent, it could be advantageous to react earlier as opposed to an interceptive task whereby there could be an optimal time to respond regardless of anticipation.

In conclusion, the integrated stereoscopic system addresses the difficulties associated with integrating the traditionally independent measurement techniques of visual-perceptual and motor skill, with the additional advantage of introducing quasi game-realistic stimulus presentations (Williams et al., 1994). Utility of the integrated stereoscopic system allows for the repeatable presentation of quasi game-realistic visual stimuli in the laboratory for assessing and training visual-perceptual-motor skill, while maintaining a higher level of ecological validity compared with traditional approaches (Gibson & Adams, 1989; Jackson & Farrow, 2005; Savelsbergh & van der Kamp, 2000). Despite no overwhelming changes in gaze behavior, significant changes in gaze fixation location were recorded when comparing the 2D and 3D conditions. Although participants fixated less on the 3D opponent's body and by inference, invested less perceptual processing toward interpreting the opponent's movements compared with the 2D condition, they performed the interception task within the same timeframe in both conditions. Three-dimensional depth cues may afford more useful information per fixation for task performance than 2D stimuli. This finding encourages further experimentation using the 3D integrated stereoscopic system for visual-perceptual-motor skill assessments/training.

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