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Integrating Advanced Visual Information with Ball Projection Technology Constrains Dynamic Interceptive Actions

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Abstract

The role of advanced visual information in ball catching was investigated by integrating video images of action and ball projection technology in four different conditions: Integrated video and ball projection (VBP), Video-Only (VO), Ball Projection-Only (BPO) and Misleading Ball projection (MBP). Hand kinematics and gaze behaviour data were collected from participants who attempted to catch balls one handed in all conditions. During VBP, catching performance was more successful, tracking of the ball occurred earlier and lasted longer, with maximum grip aperture emerging earlier with a slower maximum velocity than in BPO. During VO, movement emerged later than VBP, with larger maximum and minimum grip aperture compared to VBP and BPO. Results provided evidence that advance information, prior to ball release, and vision of a ball's trajectory are essential for successful performance and integrated projection technology may provide a representative design for studying interceptive actions.

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The concept of representative design provides a critical theoretical principle for studying human behaviour in sport (Pinder et al. 2011a). In order for perception-action coupling to be maintained, experimental task constraints need to accurately replicate those of the performance environment (Brunswick 1956). Recent empirical evidence has

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demonstrated significant changes in both movement and gaze behaviours between laboratory and representative performance contexts (Dicks et al. 2010; Mann et al. 2007; Pinder et al. 2011b). For example, in their study on soccer goalkeepers, Dicks et al. (2010) showed how gaze behaviours of individuals were clearly constrained by manipulations of experimental task constraints. In conditions which required limited participant movements (verbal response, joystick maneuvering, simplified body micro-movement); gaze was directed to the penalty kicker, yet during *in-situ* tasks participant gaze switched between the ball and the penalty kicker's motion. Goalkeepers were also more successful in judging penalty kick direction when they were required to move, compared to verbally responding. The work by Dicks et al. (2010) suggests that experimental designs and applied interventions need to move away from traditional reductionist approaches when investigating performance of dynamic interceptive movements.

For new technology to meet the requirements of representative design, Pinder et al. (2011a) highlighted two critical features, *functionality of the research* and *action fidelity*. Functionality of the task constraints allows performers to regulate actions using information sources representative of their performance environment. Hence, when researchers and coaches design practice tasks or experiments, the key perceptual variables available within the performance environments, which regulate action, must remain so that the behaviours produced can be generalised or transferred to a specific performance environment. For example, catching a ball from a thrower requires advanced information from the thrower's movement kinematics, prior to ball flight, for successful interception (Panchuk et al. 2013). When studying or practicing catching behaviours these kinematic perceptual variables must be available for participants to use, which questions the role of ball projection machines in experiments or practice tasks. Functionality has to be coupled with *action fidelity*, which is the idea that performers must be allowed to organise their own functional actions to achieve performance outcomes (e.g., organise a catching action and not verbally respond on ball flight direction) (Pinder et al. 2011a).

Here we report data from a study of dynamic interceptive actions with an integrated technological system, which combined video images of advanced visual information synchronised with ball projection. Some systems like the ProBatter (ProBatter Sports, LLC) are already being used in elite sport programs, yet there is limited empirical evidence of the advantages of such integrated systems over ball projection machines only. To test this technology an apparatus was developed to be integrated with a VICON motion capture system (Panchuk et al. 2013). Panchuk et al. (2013) showed that catching accuracy decreased along with changes in gaze behaviour when the video component of the apparatus (providing advanced visual information of a thrower's actions) was removed, supporting the need to ensure perception-action coupling. Panchuk et al. (2013) proposed that further comparative experimentation was required to understand the benefits of the integrated technology over traditional ball projection machines without integrated video systems.

The aim of this study was to establish whether the integrated video and ball projection technological system altered behaviour during a one-hand catching task, compared to three other performance conditions; (i) use of traditional ball projection machine only; (ii) video images of an individual throwing a ball, without the ball being projected, with participants simulating a catching action to the video image to replicate previous work on perceptual training that used a micro-movement response; and (iii), a 'misleading' action condition performed with the integrated video and ball projection technology where participants viewed a throwing action, without a ball being projected. The last performance condition was included to examine how prior expectation to perform a movement response (simulated vs. "real") would affect gaze behaviours. Kinematic data from hand movements and gaze behaviours in skilled catchers were studied in all four conditions.

2. Methods

2.1. Participants

Fourteen (11 male, 3 female; mean age 24.1 ± 4 years) right handed participants with normal or corrected-to-normal vision volunteered for the study. Each participant was defined as a skilled catcher by meeting the following criteria: first, all participants had at least 5 years' experience in competitive sports which involved catching projectiles such as cricket, basketball or handball (obtained via a sport participation questionnaire). Second, during a pre-test they were required to successfully catch at least 16 out of 20 ($M = 18.14 \pm 1$) balls. Skill level was confirmed by the overall success rate of catching during the experimental task ($M = 91\% \pm 4\%$). Institutional

ethical approval was granted by the Research Ethics Committee and all participants provided informed consent prior to participation.

2.2. Apparatus

A custom-built apparatus was designed to integrate a ball projection machine (Spinfire Pro 2, Spinfiresport, Tennis Warehouse, Victoria, Australia) with a PC (Windows XP, Microsoft, USA), video projector (BenqMP776S, Benq, Australia) and a free standing projection screen (Grandview, Grandview Crystal Screen, Canada) (for a detailed overview see Panchuk et al. 2013). The apparatus enabled video projection onto a free standing screen with a 15cm hole cut into it, allowing video to be synchronised with ball projection.

Video images of an actor throwing a ball were captured from the perspective of a participant standing in front of the screen. Five video clips that captured the actor throwing a ball at a speed of 50 ± 2 km/h and accurately hitting a target of 1 m x 1 m were selected. These images were selected to ensure the throwing action was consistent across all trials (no participants reported that the images were being repeated). A test film of 100 trials was created consisting of; 30 Ball Projection-Only trials (BPO) where only the ball was projected from the machine without any video shown; 30 Video-Only (VO) trials were included, where the video was shown without the ball being projected; and 30 trials of Video and Ball Projection (VBP) which combined video images of advanced visual information from a thrower's actions synchronised with ball projection. Finally, within the VBP trials, an additional 10 trials from a 'misleading' ball projection (MBP) condition were presented where a ball was not projected, although participants expected a ball to be released. The MBP trials were organised randomly within the VBP trials sequence and kept consistent across participants. Final Cut Pro (Apple, California, USA) was used to edit footage so the spatial location of the ball release occurred at the same position in each trial. The time to ball release was recorded and temporally aligned with the software so that ball release by the thrower and the actual projection of the ball occurred simultaneously.

Kinematic data were collected using a VICON MX System consisting of 10 MX-T 40S cameras recording data at 500Hz using a common, commercially available kinematic gait model and marker set (Plug-In-Gait, VICON, Peak, Oxford, UK). Additionally, two markers were placed on the end of the right distal phalanges of the index finger and thumb of participants. A mobile eye tracking device (Mobile Eye, Applied Sciences Laboratories, Bedford, MA) was worn by each participant during the catching task. The system uses corneal reflection to measure monocular eye-line-of-gaze in relation to field of view with spatial accuracy of 0.5° and precision of 0.1° .

2.3. Procedure

First, sport participation questionnaires were completed and an overview of the apparatus was provided. Three practice trials at projection speeds of 50 km/h were performed, followed by the 20 trial pre-test of catching skill. Reflective markers were then attached using double-sided tape in line with Plug-In-Gait guidelines. A mobile eye tracking system was fitted and calibrated using 5 points projected on the video screen and calibration was continually monitored throughout testing. Participants were given a further 5 trials to become familiarised with the equipment and ensure synchronisation was functioning correctly. The experiment consisted of three blocked conditions performed using a counterbalanced design: BPO, VO and VBP (including 10 MBP trials). Participants were asked to catch the ball during BPO and VBP and to simulate a catch during VO trials by timing and placing their hand at the location where they expected the ball to be projected.

Participants stood 7 m away from the screen in a relaxed position, hand by side, feet shoulder width apart and attempted to catch the ball with their right hand. When ready, the ball was fed into the projection machine and, after a random interval between 0-3 seconds, the apparatus was activated and video and ball were projected depending on the experimental condition. Other than being asked to catch the ball no other specifying instructions were given in relation to gaze or movement behaviours. The outcome of the trial was recorded by two researchers to ensure reliability. A 2-5 minute break was given between trial blocks to prevent fatigue. None of the participants reported any discomfort or impediment to catching the ball with the equipment. Participants wore ear plugs to prevent them using acoustic information from the apparatus to time their actions.

Data processing and analysis

Of a total of 1,400 trials captured across all participants, 32 trials (2.3%) of kinematic data were removed from analysis due to technical faults and one participant's eye movement data were removed due to calibration issues. Each performance outcome was recorded as a catch or drop, with success rate expressed as a percentage of trials. A Butterworth filter, set to a cut-off frequency of 8 Hz, was used to smooth kinematic data. The hand marker was used to calculate Movement Onset (T_{on}) and defined as the time from the start of the trial until a change in hand velocity threshold of 5 m/s or greater. Maximum (Max) Velocity was calculated as the Max velocity of the hand after being temporally realigned to T_{on} . Max grip aperture (MaxGA) was the maximal distance between the thumb and finger markers after movement onset. Minimum grip aperture (MinGA) was the minimal distance between the thumb and finger markers measured after MaxGA and represented the point the ball was caught. Time to Max (TMaxGA) and Min (TMinGA) grip aperture were determined relative to movement onset. Total time to MinGA was defined from the start of the trial to min grip aperture, showing time from trial start until ball contact/catch. Differences between TMaxGA and TMinGA (Diff-TMaxGA-TMinGA) were calculated by subtracting TMinGA from TMaxGA. Gaze data were coded frame-by-frame with fixations and tracking behaviour coded when the gaze cursor remained within 3^0 of visual angle of a location or moving object for a minimum of three frames of video (100ms; after Vickers 2007). Six gaze locations were identified for all conditions: head, body, throwing arm/hand, release point (ball projection machine hole), ball and 'other' (after Panchuk et al. 2013). The 'other' category was used when gaze fell on a location previously not identified. Total time fixating on each location was calculated as a percentage (total time fixating on each location \div total trial time \times 100). Fixations per second were the total number of fixations completed during each trial divided by total trial time. Tracking latency was determined by calculating the duration between time of ball release and onset of ball tracking. This was also expressed as a percentage of total ball flight time. Intra-Code reliability was determined using 20 randomly selected trials for fixation onset, offset and number of fixations. Code-recode reliability was $r = .97$. Dependent measures t-tests were performed on catching accuracy, tracking latency and tracking duration between VBP and BPO. A repeated measures ANOVA was used to analyse fixations per second in each condition. Percentage viewing time data was arcsine transformed, then a two-way repeated measures ANOVA was used to analyse percentage viewing time (4 Performance conditions \times 7 Locations). Kinematic variables (T_{on} , Max Velocity, MaxGA, MinGA, TMaxGA, TMinGA, Diff-TMaxGA-TMinGA) were analysed across each performance condition using separate repeated measures ANOVAs. MBP was removed from kinematic analysis as participants did not complete the full catching action. A Greenhouse Geisser correction was applied to any violations of sphericity. Post-hoc testing used a Bonferroni correction. Partial eta squared (η_p^2) was used for effect size estimations of main effects on ANOVAs with Cohen's d presented, when appropriate, for t-tests and post-hoc analyses.

3. Results

Performance condition (Pcondition) affected catching outcomes $t_{1,13} = 2.226$, $p < .05$, $d = .75$ with $94.3\% \pm 4.6\%$ of balls successfully caught during VBP compared to $88.3\% \pm 10.2\%$ during BPO. A summary of descriptive statistics and post-hoc differences for all kinematic variables are shown in Table 1.

Table 1. Movement Kinematics during experimental conditions (Mean \pm SD)

	BPO	VO	VBP
T_{on} (ms)	1897 \pm 267	2110 \pm 365 ^a	1833 \pm 252 ^a
Max Velocity (m/s)	29.31 \pm 6.29 ^a	30.05 \pm 8.15 ^b	24.38 \pm 5.91 ^{ab}
MaxGA (cm)	10.31 \pm 1.67 ^a	12.84 \pm 3.45 ^{ab}	10.10 \pm 1.98 ^b
MinGA (cm)	5.14 \pm 1.04 ^a	8.44 \pm 3.15 ^{ab}	5.75 \pm 1.46 ^b
TMaxGA (ms)	312 \pm 33 ^a	324 \pm 185	221 \pm 111 ^a
TMinGA (ms)	471 \pm 191	666 \pm 320 ^a	385 \pm 135 ^a
Diff-TMaxGA-TMinGA (ms)	159 \pm 179	342 \pm 209 ^a	164 \pm 48 ^a
Total Time MinGA (ms)	2369 \pm 310 ^a	2776 \pm 341 ^b	2219 \pm 272 ^{ab}

^a denotes first significant comparison, ^b denotes second significant comparison (post-hoc differences ($P < .05$))

Pcondition had a main effect on T_{on} $F_{1,155, 15.02} = 5.692$, $p < .05$, $\eta^2 = .29$ with post-hoc tests showing earlier onset during VBP than VO, $p < .05$, $d = .88$. Pcondition had a main effect on max velocity $F_{1,281,16.658} = 5.613$, $p < .05$, $\eta^2 = .30$ with post-hoc tests showing both BPO and VO had greater velocities compared to VBP (both $p < .05$, $d = .81$ and $d = .79$ respectively). Pcondition had a main effect on MaxGA $F_{2, 26} = 9.747$, $p < .001$, $\eta^2 = .43$, with post-hoc analyses showing a larger aperture used by participants during VO than in BPO and VBP (both $p < .05$, $d = 0.93$, $d = .97$ respectively). Pcondition had a main effect on MinGA $F_{1,349, 17.532} = 9.869$, $p < .05$, $\eta^2 = .48$ with post-hoc tests revealing smaller grip apertures for BPO and VBP than VO (both $p < .05$, $d = 1.41$ and $d = 1.2$ respectively). Pcondition had a main effect on TMaxGA $F_{2, 26} = 3.491$, $p < .05$, $\eta^2 = .21$ with post-hoc tests showing performance in VBP to be quicker than in BPO $p < .05$, $d = .67$. Pcondition had a main effect on TMinGA $F_{2, 26} = 6.413$, $p < .01$, $\eta^2 = .33$ with post-hoc tests showing this occurred earlier in VBP than VO, $p < .05$, $d = 1.15$. Pcondition had a main effect on Diff TMaxGA-TMinGA $F_{1,419, 18.448} = 5.414$, $p < .05$, $\eta^2 = .29$, with post-hoc tests showing a smaller difference during VBP than VO $p < .05$, $d = 4.53$. Finally, Pcondition had a main effect on TotalTMinGA $F_{2,26} = 30.452$, $p < .001$, $\eta^2 = .70$, with post-hoc tests showing this occurred earlier in VBP and BPO than VO both $p < .001$, $d = 1.80$, $d = 1.25$ respectively.

Analysis of gaze behaviours showed that Pcondition also affected tracking latency, $t_{1, 12} = 2.751$, $p < .05$, $d = 1.02$ with tracking occurring later during BPO (182ms \pm 41ms), compared to VBP (133ms \pm 54ms). Pcondition also effected tracking duration, $t_{1, 12} = -2.830$, $p < .05$, $d = .87$, with shorter tracking duration in BPO (231ms \pm 54ms) compared to VBP (281ms \pm 61ms). Pcondition also produced differences in the percentage of ball flight tracked, $t_{1,12} = 3.259$, $p < .01$, $d = 1.26$ with tracking occurring for a greater percentage of time during VBP (57.43% \pm 9.95%) compared to BPO (44.59% \pm 10.4%). Pcondition had a main effect on total fixation per second, $F_{3, 36} = 13.26$, $p < .001$, $\eta^2 = .53$. Post-hoc tests showed that more fixations were made in both VBP (1.784 \pm 0.41) and VO (1.695 \pm 0.41) compared to BPO (1.072 \pm 0.16) (both $p < .001$, $d = 2.29$, $d = 1.52$ respectively). There were also more fixations per second made in VBP (1.784 \pm 0.41) than MBP (1.474 \pm 0.54) $p < .05$, $d = .64$.

The two-way repeated measures ANOVA revealed Pcondition had no main effect on percentage viewing time ($p > .05$). However, there was a main effect of location on percentage viewing time, $F_{1,765, 21.186} = 71.766$, $p < .01$, $\eta^2 = .86$. Release point was different to all other locations (all $p < .001$) with more time spent fixating on the release point (53.6%), than head (9.8%), body (4.2%), throwing arm (13.9%), ball (7.0%) and other (1.3%) locations. Differences were also shown between body (4.2%) and throwing arm (13.9%) ($p < .05$), throwing arm (13.9%) and other (1.31%) ($p < .001$), and ball (7.0%) and other (1.31%) ($p < .001$). There was also a Location x Condition interaction $F_{4,284, 51.408} = 32.02$, $p < .01$, $\eta^2 = .55$, illustrated in Figure 1. Participants spent a greater proportion of time fixating on the release point in the BPO (73.3% \pm 5.6%) condition in comparison to the VO (36.82% \pm 25.7%, $d = 1.95$), VBP (49.6% \pm 22.7%, $d = 1.42$), and MBP (54.4% \pm 23.8%, $d = 1.07$).

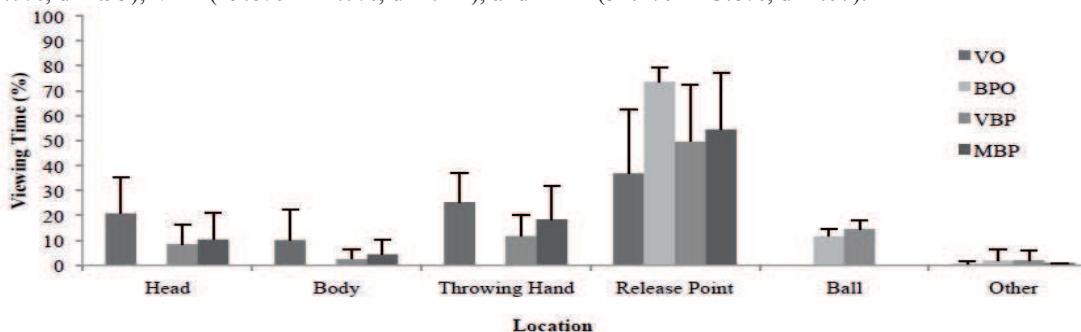


Figure 1. Time (%) spent fixating different location across 4 conditions (VBP, VO, BPO, MBP)

4. Discussion

This study integrated advanced perceptual information with ball projection technology to investigate how actions were constrained during projectile interception. Catching performance was more successful with integrated video and ball projection technology compared to when only ball flight information was available, providing evidence that advanced perceptual information aids catching performance. These comparisons also revealed that gaze behaviours differed, with more fixations made, tracking of the ball occurring earlier, and for a longer time. Hand kinematics analysis also showed a smaller Max velocity value and quicker time to MaxGA with integrated

technology compared to ball projection machine only. Findings revealed that advanced visual information is a considerable constraint on performance of interceptive actions, suggesting why ball projection technology should be integrated with video images of pre-ball flight events/movements. Without integrated video images participants were unable to perceive the affordances from the advanced visual information, requiring them to rely on ball flight information only to constrain their actions. With additional perceptual information provided by integrating video images of action with ball projection technology, individuals could use advance visual information and track the ball to enable more controlled hand movements resulting in more successful catches. Despite the number of fixations per second being similar between VO and VBP, and both greater than in BPO, this visual information was not used to simulate an effective movement without the use of ball flight information. With video images only, movement onset occurred later than in the integrated condition, resulting in higher maximum hand velocity. A critical component of successful catching, the grasping action, was also undertaken considerably differently when the ball was projected with greater MaxGA and MinGA during VO compared to VBP and BPO. The greater MinGA and later TMinGA suggesting if a ball were being projected, the participants would not have timed their actions or have had a strong enough grasp to catch and hold the ball. These findings highlight the role of ball flight information to guide both the timing of arm movement and the correct grip aperture during catching performance.

In combination, the findings across the three conditions support van der Kamp et al.'s (2008) proposal that both advanced information prior to ball release and ball trajectory information are essential for successful performance, with both having a considerable influence on constraining action. The findings have implications for studies and applied interventions which neglect to include a movement component (action fidelity) or fail to provide advanced perceptual information (functionality) for performers. Removal of either alters the informational constraints available and fails to adequately capture the dynamic, emergent nature of interceptive actions. For example, attempts to train perception, with limited involvement of necessary actions, may improve decision-making under those specific task constraints, yet it is unlikely the movements required to act on such decisions will be improved.

The combination of more fixations per second during VO than BPO and the Location x Condition interaction suggested that changes in fixation location depend on the informational constraints presented during experiments or training programmes. This finding provides further evidence that gaze behaviours change depending on the visual information available (Dicks et al. 2010; Mann et al. 2007; Pinder et al. 2011b). The data has implications for the design and implementation of ball projection machines. Prolonged training with them may result in individuals gaining extensive experience performing with such technology, but is likely to result in the development of a dependence on informational constraints that may not be reliable in the performance environment, especially against high projectile velocities (e.g., cricket fast bowling). However, some caution must be applied in interpreting these data as the ball projection release point was the most fixated location in all performance conditions. Even during the VO condition, participants spent the highest percentage of time focusing on the projection release point despite knowing that no ball would be released. This could suggest participants used the release point as a pivot or anchor for their gaze, switching to key areas then focusing back onto the release point, or using their peripheral vision to gain extra information while fixating the release point. In conclusion, the results showed that the integrated ball projection technology presented here may be a useful tool to increase representative design both for experimental tasks and practice in ball sports over traditional methods.

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