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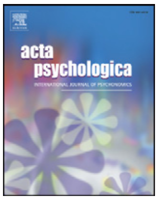

Temporal and spatial occlusion of advanced visual information constrains movement (re)organization in one-handed catching behaviors

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ABSTRACT

Dynamic interceptive actions are performed under severe spatial and temporal constraints. Here, behavioral processes underpinning anticipation in one-handed catching were examined using novel technology to implement a spatial and temporal occlusion design. Video footage of an actor throwing a ball was manipulated to create four temporal and five spatial occlusion conditions. Data from twelve participants' hand kinematics and gaze behaviors were recorded while attempting to catch a projected ball synchronized with the video footage. Catching performance decreased with earlier occlusion of the footage. Movement onset of the catching hand and initiation of visual ball tracking emerged earlier when footage of the thrower was occluded at a later time point in the throwing action. Spatial occlusion did not affect catching success, although movement onset emerged later when increased visual information of the actor was occluded. Later movement onset was countered by greater maximum velocity of the catching hand. Final stages of action (e.g., grasping action of the hand) remained unchanged across both spatial and temporal conditions suggesting that later phases of the action were organized using ball flight information. Findings highlighted the importance of maintaining information-movement coupling during performance of interceptive actions, since movement behaviors were continuously (re)organized using kinematic information from a thrower's actions and ball flight information.

1. Introduction

Dynamic interceptive actions, such as catching a moving object, are performed under severe spatial and temporal constraints with a margin of error for interception during catching of only ± 15 ms even at a moderate speed of 10 m/s (Alderson, Sully, & Sully, 1974). A critical factor in countering these demands is the ability to anticipate event outcome, since waiting for information available after a projectile has been hit, struck or kicked may result in insufficient time to successfully perform the interceptive action (van der Kamp & Renshaw, 2015). Evidence supporting this proposal has come from experiments using occlusion paradigms, which require participants to anticipate while viewing video footage that has been edited to occlude actions at different time points (temporal occlusion) or different features within the display (spatial occlusion) (Abernethy & Russell, 1987; Müller, Abernethy, & Farrow, 2006; Shim, Carlton, Chow, & Chae, 2005).

Despite the considerable body of research investigating pre-ball release behaviors, researchers employing occlusion paradigms have typically overlooked the role of movement organization in interceptive actions. Instead the preferred focus has been on *perceptual judgments* of the predicted direction in which a participant *might have moved* or where a ball *might land*, or on reactive *micro-movements* (very simplified responses such as stepping or pointing in a specific direction) (e.g. Brenton, Müller, & Mansingh, 2016; Farrow, Abernethy, & Jackson, 2005; Müller et al., 2006). The spatio-temporal (re)organization of coordination patterns, however, appears to be an important factor in anticipation timing as skilled performance differences become more pronounced when actual dynamic interceptive actions are performed in comparison to reactive micro-movements (Travassos, Davids, Araujo, & Esteves, 2013).

The theoretical approach of ecological psychology, highlights the importance of studying animal-environment relations and emphasizes the reciprocal relationship between perception and action (Gibson, 1979; Michaels & Carello, 1981; Warren, 2006). Seminal work in ecological psychology has highlighted the need to design experimental conditions that sample representative information from an organism's environment, and which involve research designs that allow participants to

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organize functional movement behaviors (i.e., predicated on information-movement coupling; see Brunswik, 1956; Gibson, 1979; Warren, 2006). One attempt to support information-movement coupling in research designs employing occlusion paradigms has been the use of micro-movements or simulated responses to occluded video footage of opponents. However, evidence from behavioral neuroscience has demonstrated that simulated (micro) movements engage different neural processes compared to performing actual interceptive actions (for examples see Króliczak, Heard, Goodale, & Gregory, 2006; Króliczak, Cavina-Pratesi, Goodman, & Culham, 2007).

A challenge for researchers examining the nature of movement (re)-organization processes is to allow representative interceptive actions to emerge while controlling the information sources available to participants. To address this issue, Stone et al. (2014a) developed an integrated video and ball projection machine enabling rigorous control of pre-ball release visual information while supporting a fully coupled interceptive action that was representative of actual performance. Integrated video and ball projection technology allowed participants access to the kinematic information from a thrower's action and to also organize a physical catching action to intercept a ball projected through a hole cut into a screen (see Stone et al., 2014a for a detailed description).

Using this integrated video and ball projection machine, the importance of both advanced visual information from the kinematics of a throwing action and ball flight characteristics in supporting successful catching performance has been reported (Panchuk, Davids, Sakadjian, MacMahon, & Parrington, 2013; Stone, Panchuk, Davids, North, & Maynard, 2014b). Both advanced visual information prior to ball release and subsequent ball flight information have been demonstrated as critical for the (re)organization of catching behaviors using the integrated video and ball projection technology (Panchuk et al., 2013; Stone et al., 2014b; Stone, Panchuk, Davids, North, & Maynard, 2015). Currently, however, there have been no attempts to use integrated technology that provides rigorous control of advanced visual information, which can be spatially and temporally occluded, facilitating analysis of the (re)organization of actions for catching a ball, compared to a reactive micro-movement. This approach would allow detailed investigation in to how different aspects of perceptual information constrain actions and their organization.

In the present study, therefore, we sought to examine how temporal and spatial occlusion of video images of a person throwing a ball shaped movement organization and gaze behaviors during one-handed catching. Similar to previous studies with temporal occlusion paradigms, we occluded the video images of the actor at different kinematic stages of the action (e.g. movement initiation, lead foot contact, arm acceleration and ball release, Cook & Strike, 2000) to examine how altering the amount of pre-ball release kinematic information available shaped movement behaviors. Based on previous research by Stone et al. (2014b), we hypothesized that tracking latency and time of movement onset would be scaled to visual information available, emerging later when temporal occlusion occurred earlier. These informational constraints were expected to result in participants tracking less of the ball flight and producing higher maximum velocity of the hand to ensure it was in the correct location at the point of ball impact. In turn, as a consequence of these behavioral changes, we expected that catching performance would be less successful when visual information was occluded at an earlier time point, compared to when video images of the full throwing action were available. We also predicted that maximum and minimum grip aperture of the catching hand would be unaffected by temporal occlusion conditions as this action component, occurring later in the catching action, would be adapted to *ball flight* rather than *video image*

Under spatial occlusion task constraints, we removed images of specific sections of the actor's body to manipulate the amount of specifying information available. Previous research that has reported visual search data in catching tasks has highlighted that people use the upper body and throwing arm as the most specifying information sources (see Stone et al., 2014b, 2015). We created five conditions, predicting that, when more specifying (regulatory) information from the video, for example from the upper body or throwing arm was occluded, time of movement onset and tracking latency would emerge later, resulting in a greater maximum hand velocity, and reduced time spent visually tracking the ball. In line with the hypotheses for temporal occlusion conditions, these adaptive movement behaviors were also expected to result in decreased catching performance. However, it was expected that maximum and minimum grip apertures in the grasp phase would be adapted to ball flight information and would remain the same across the different spatial occlusion conditions.

2. Method

2.1. Participants

Twelve (10 men, 2 women; mean age 24.3 ± 4 years, stature 1.76 ± 0.06 m and body mass 79.8 ± 10.7 kg) right-handed, skilled catchers volunteered to participate in the study. Participants were defined as skilled because they had at least 5 years' experience in sports requiring catching projectiles such as cricket, handball or Australian Rules football (reported via a sport participation questionnaire). Additionally, during a pre-test, participants had to catch at least 16 out of 20 balls (Mean = 18.1 ± 1) projected at 13.9 m/s, standing 7 m from the ball projection machine. Skill level was confirmed by the high overall catching success level of participants across all experimental conditions (Mean = 92.0 ± 2.6%). Institutional ethical approval was granted by a University Research Ethics Committee and all participants provided informed consent.

2.2. Apparatus

A custom-built apparatus integrated 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 freestanding projection screen (Grandview, Grandview Crystal Screen, Canada) with a 15-cm hole cut into the screen (see Stone et al., 2014a for a detailed description). The integrated technology allowed video images of an actor throwing a ball to be projected onto a screen and synchronized with balls being projected through the hole cut into the screen. Video images of an actor throwing a ball from the participants' perspective were recorded with ball speeds measured using a radar gun. Throwing accuracy of the video images was ensured by only including film of trials when the thrown ball hit a 1 m × 1 m target at a speed of 13.9 ± 0.5 m/s. This speed value corresponded to a ball speed setting on the projection machine of 14 ± 0.2 m/s. Ten video clips (5 for temporal, 5 for spatial occlusion conditions) were selected to ensure video presentation of consistent kinematics of the thrower's action. Final Cut Pro software (Apple, California, USA) was used to edit footage so that time to ball release was recorded and aligned to ensure accurate synchronization of the image of the thrower's release and the projection of a ball (mid-pressed tennis balls, 66 mm diameter) from the machine (for details see Stone et al., 2014a). Final Cut Pro was then used to edit the videos to create four temporal and five spatial occlusion conditions.

The four temporal occlusion conditions were edited so that video information was removed and replaced by a blank screen at the point of occlusion. These time points were selected by adapting Seroyer et al. (2010) kinetic chain of overhand pitching and inline with the main kinematic phases of an overarm throwing action being movement initiation, lead foot contact, arm acceleration and ball release (see Cook & Strike, 2000; Leudke, 1981; Feltner, 1989).

Condition T1 was occluded at the point when the ball was below the waist (start of arm movement) representing the point of movement initiation. The next stage condition T2, was defined as the lead foot contact or step/early ‘cocking’ phase of the throwing action, with the video