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Continuous visual control of interception

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ABSTRACT

People generally try to keep their eyes on a moving target that they intend to catch or hit. In the present study we first examined how important it is to do so. We did this by designing two interception tasks that promote different eye movements. In both tasks it was important to be accurate relative to both the moving target and the static environment. We found that performance was more variable in relation to the structure that was not fixated. This suggests that the resolution of visual information that is gathered during the movement is important for continuously improving predictions about critical aspects of the task, such as anticipating where the target will be at some time in the future. If so, variability in performance should increase if the target briefly disappears from view just before being hit, even if the target moves completely predictably. We demonstrate that it does, indicating that new visual information is used to improve precision throughout the movement.

1. Introduction

In general, people look at objects when they interact with them or intend to interact with them (Horstmann & Hoffmann, 2005; Johansson, Westling, Backstrom, & Flanagan, 2001; Land & Hayhoe, 2001; Mennie, Hayhoe, & Sullivan, 2007; Pelz, Hayhoe, & Loeber, 2001; Rothkopf, Ballard, & Hayhoe, 2007). This is also true when intercepting moving objects (Bahill & LaRitz, 1984; Brenner & Smeets, 2007, 2009; Mrotek & Soechting, 2007; Soechting & Flanders, 2008). However, the extent to which pursuing a target is essential for catching or hitting is not yet clear (Brenner & Smeets, 2010; Dessing, Oostwoud Wijdenes, Peper, & Beek, 2009; Sharp & Whiting, 1974, 1975). There are several reasons why it may be advantageous to keep one's eyes on the target (Wilmut, Wann, & Brown, 2006). The

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most obvious one is that doing so ensures that the resolution with which the visual information is acquired is maximal. We here evaluate whether this is the main reason for doing so.

Keeping the fovea directed at the ball ensures that one has access to the highest possible spatial resolution when localising the ball and judging its trajectory. This is probably particularly important if the ball's trajectory is not completely predictable, so that one must constantly consider whether one needs to adjust one's movement. If it is likely that the movement will have to be adjusted at a certain moment, such as occurs when one can anticipate that the ball will bounce off an uneven surface, people make sure to have their eyes on the ball at that moment (Land & McLeod, 2000). If the trajectory is predictable, it is probably less important to have the highest possible spatial resolution throughout the movement. Indeed, for reasonably predictable trajectories of a ball, it is not even necessary to see the entire trajectory in order to catch the ball (e.g., López-Moliner, Brenner, Louw, & Smeets, 2010; Whiting & Sharp, 1974). The extent to which vision at various moments is essential for successful interception is widely debated (e.g., Bootsma & van Wieringen, 1990; Dubrowski, Lam, & Carnahan, 2000; Marinovic, Plooy, & Tresilian, 2009; Müller & Abernethy, 2006; Sharp & Whiting, 1974; Teixeira, Chua, Nagelkerke, & Franks, 2006; van Soest et al., 2010; Young & Zelaznik, 1992). If there are moments at which visual information is not very important, it is also unlikely to be necessary to pursue the target at such moments.

We recently proposed that even for completely predictable target motion it is advantageous to keep one's eyes on the target throughout the movement (rather than only at the start), because if one maintains a high visual resolution, the accuracy with which one can predict where the target will be when one reaches it will keep increasing as the movement progresses (Brenner & Smeets, 2009). Directing one's gaze towards the target early in the movement helps ensure that the movement starts off more or less correctly, so that only modest adjustments are later needed, and keeping one's eyes on the target ensures that such modest adjustments are based on increasingly accurate estimates as the duration of the prediction decreases because the hand approaches the target. The first experiment of this study was designed to directly examine to what extent pursuing the target with one's eyes until one hits it is beneficial when intercepting targets that move in a completely predictable manner.

2. Experiment 1: eye movements

Virtual targets moved from left to right at a constant velocity across a surface. They were to be hit with a stylus. The stylus was initially at a starting point near the subject's body. When intercepting such targets, subjects tend to pursue the target with their eyes for most of the time (Brenner & Smeets, 2007, 2009). Even if subjects are explicitly instructed to fixate a static point, they cannot avoid following the moving target with their eyes just before hitting it (Brenner & Smeets, 2010). Moreover, even if we could train subjects not to pursue the target, adding such a second task could influence subjects' precision (Wilmut et al., 2006). We therefore wanted to influence the eye movements without any explicit instructions or constraints. To do so we compared interception in two slightly different tasks that required a similar spatial and temporal accuracy, but were designed to give rise to different eye movements: hitting a small target into a gap and hitting a target through a small gap.

We reasoned that subjects would want to direct their gaze towards the smallest relevant structure, which would be the small target when the task was to hit the moving target into the larger gap, but would be the small gap when the task was to hit through the static gap just as the larger target passes behind the gap. In these tasks the smallest structure was also the first one that the subject's hand encounters, which is also likely to encourage them to direct their gaze towards it. We expect this to have consequences for the precision of their hand movements, which we expect to be highest in relation to the structure that they are looking at.

2.1. Methods

2.1.1. Equipment

The setup and tasks are shown schematically in Fig. 1. Images were projected at 85 Hz and a resolution of 1024 by 768 pixels onto a back-projection screen that was 20 cm above a half-silvered