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Is perception of self-motion speed a necessary condition for intercepting a moving target while walking?

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HIGHLIGHTS

- Perceiving self-motion velocity is not a *sine qua non*-condition for interception.
- This study illustrates the flexibility of the perceptual-motor strategies involved.
- The role of Global Optic Flow Rate depends on the informational context.

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ABSTRACT

While it has been shown that the Global Optic Flow Rate (GOFR) is used in the control of self-motion speed, this study examined its relevance in the control of interceptive actions while walking. We asked participants to intercept approaching targets by adjusting their walking speed in a virtual environment, and predicted that the influence of the GOFR depended on their interception strategy. Indeed, unlike the Constant Bearing Angle (CBA), the Modified Required Velocity (MRV) strategy relies on the perception of self-displacement speed. On the other hand, the CBA strategy involves specific speed adjustments depending on the curvature of the target's trajectory, whereas the MRV does not. We hypothesized that one strategy is selected among the two depending on the informational content of the environment. We thus manipulated the curvature and display of the target's trajectory, and the relationship between physical walking speed and the GOFR (through eye height manipulations). Our results showed that when the target trajectory was not displayed, walking speed profiles were affected by curvature manipulations. Otherwise, walking speed profiles were less affected by curvature manipulations and were affected by the GOFR manipulations. Taken together, these results show that the use of the GOFR for intercepting a moving target while walking depends on the informational content of the environment. Finally we discuss the complementary roles of these two perceptual-motor strategies.

1. Introduction

Control laws reflect the operation of perceptual-motor principles and allow agents to perform a given task under a wide variety of conditions. Morice et al. [1] questioned the robustness of the Constant Bearing Angle (CBA) control law for the control of interceptive tasks performed by humans. This study showed that the CBA strategy accounted for the speed profiles of agents who intercepted approaching targets under changing task and environmental constraints. According to this law [1,2], maintaining constant the bearing angle subtended by the current position of the target and the direction of the displacement of the observer (Fig. 1A) leads to the interception of the target (Eq. (1)):

$$\ddot{Y} = \frac{1}{1+200 \times e^{-10t}} \times k_1 \times \dot{\theta} + k_2 \times \dot{Y} \quad (1)$$

where $\ddot{Y}$ is the walking acceleration (m/s^2). $\dot{Y}$ the walking speed (m/s), $\dot{\theta}$ the rate of change of the bearing angle (°/s), k_1 and k_2 parameters modulating the strength of the coupling between $\ddot{Y}$ and $\dot{\theta}$ and modulating the strength of the damping term, respectively. $1/(1+200 \times e^{-10 \times t})$ is an activation function.

However, Morice et al. [1] evidenced that participants did not always rely on the CBA strategy. The study also evaluated the effects of displaying the future trajectory of the target. The CBA strategy predicts that manipulation of the curvature of the target trajectory should have a specific influence on speed adjustments. On the other

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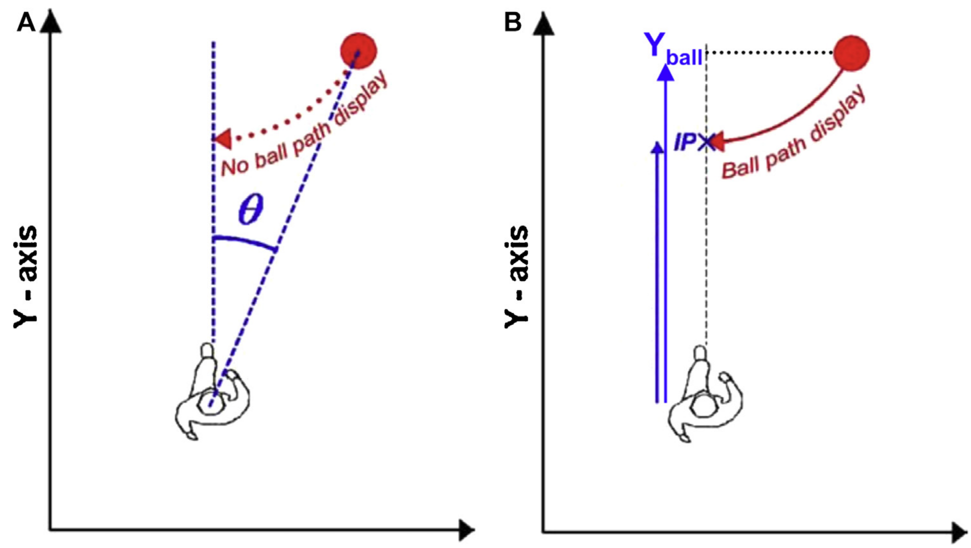

Fig. 1. Schema of the experimental layout. Participants walked on a rectilinear path toward balls that traveled toward their displacement axis. (A) The natural informational content of the agent–ball environment includes the bearing angle (θ), which forms the informational support for the CBA strategy. (B) When the ball track is displayed onscreen, the informational content of the visual scene is enriched relative to natural conditions. The distance to the interception point (*IP*) is part of the informational support for the MRV strategy.

hand, displaying the future trajectory of the target should not affect how agents regulate their behavior as it does not affect the rate of change in bearing angle. Their results supported the idea that the CBA strategy was used when the future trajectory was not shown, as manipulating the curvature did influence speed adjustments as predicted. In contrast, when the target trajectory was shown, curvature manipulations had less of an influence on walking speed. Moreover, under these conditions a Modified Required Velocity (MRV) strategy (Eqs. (2) and (3)) provided a better explanation of how behavior is regulated than the CBA strategy. According to the MRV strategy [1], agents should accelerate at a rate that depends on the difference between the physical and the required speed:

$$\ddot{Y} = k_1 \times (k_2 \times \dot{Y}_{req} - \dot{Y}) \quad (2)$$

$$\dot{Y}_{req} = \frac{Y_{IP} - Y}{TTC} \quad (3)$$

where Y, $\dot{Y}$, and $\ddot{Y}$ are the agent's physical position, speed, and acceleration respectively, $\dot{Y}_{req}$ the required walking speed, Y_{IP} the future interception position, *TTC* the time remaining before the target reaches Y_{IP}, and k_1 and k_2 constants (Fig. 1B).

The Morice et al. study [1] therefore identified the boundary conditions in which the CBA strategy operates, and its results are compatible with an information-driven switch between two control laws. Because the MRV strategy (unlike the CBA strategy) takes into account the agent's perception of their walking speed (Eq. (2)), a more direct and elegant test of the MRV strategy is to manipulate the optical correlates of self-motion speed.

It is now well-established that agents use the Global Optic Flow Rate (GOFR) to judge their displacement [3,4] and control their speed while performing a perceptual-motor task [5,6]. The GOFR corresponds to the (average) angular speed of texture elements in the environment. It is inversely proportional to eye height and independent of texture density. François et al. [6] confirmed that biasing the GOFR led to large changes in walking speed. Nevertheless, the question remains as to whether the perception of self-displacement is used to control walking speed in a task in which the primary goal is to intercept a moving target, rather than maintain a constant speed (e.g., preferred walking speed).

In our experiment we biased the GOFR while participants attempted to intercept a moving ball. If it is the case that the MRV strategy is used in enriched environments, biasing the GOFR (i.e., optical correlate of $\dot{Y}$ in Eq. (2)) should result in specific speed profiles. Conversely, in the normal environment this manipulation should not affect how participants regulate their behavior, as they are expected to rely on the CBA strategy (cf., Eq. (1)), which does not depend on the perception of self-motion speed.

2. Materials and methods

2.1. Participants

Eight male students (mean age 22.75 ± 2.86 years) gave their informed consent before participating in the experiment. They all had normal or corrected-to-normal vision. A local ethics committee approved the experimental protocol.

2.2. Apparatus

The virtual reality set-up (Fig. 2A) consisted of two host computers, a treadmill, a video projector, and a 3.0 m wide × 2.3 m high projection screen. Participants walked on the treadmill, equipped with a 0.80 wide × 1.96 long moving belt sliding over a flat and rigid surface. They wore earmuffs in order to prevent them from

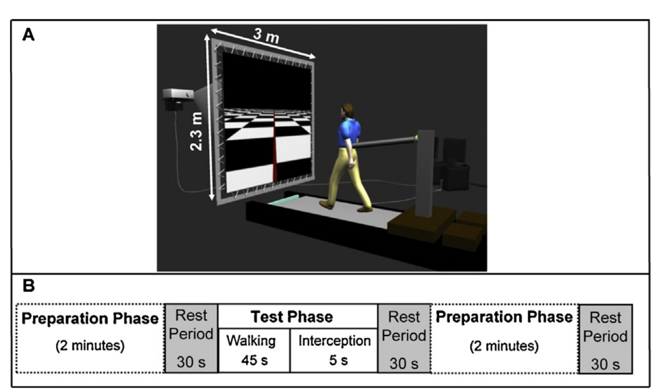

Fig. 2. (A) Overview of the virtual reality set-up and the visual scene that was projected onto the screen in front of participants; (B) experimental phases.