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The perceptual support of goal-directed displacement is context-dependent

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Abstract

This study investigates the perceptual-motor organisation underlying the control of goal-directed displacement. We used a virtual reality set-up to study the locomotor interception of a moving ball. Subjects had to intercept moving balls by modifying displacement velocity if necessary, while the ball's place of arrival and the environment were manipulated. The results showed that subjects simultaneously managed multiple sources of information and placed priority on the most salient variables, depending on the task and environmental constraints.

Keywords: Perceptual variables; Visual control; Bearing angle; Goal-directed displacement; Optic flow; Egocentric direction; Vision; Proprioception

The perceptual-motor mechanisms underlying goal-directed displacement have received a great deal of attention in the last decade [4,9,14]. Whether they required the actor to regulate displacement direction [17,19] or displacement velocity [3], these studies have all shown that displacement control entails the simultaneous use of different perceptual variables. Whenever possible, actors seem to make use of various kinds of perceptual regularities in the unfolding action [2].

In this study, we used a virtual reality set-up to examine the locomotor interception of a moving ball. The actor moved along a straight path (by manipulating a joystick) and could freely modify forward velocity, if necessary, in order to intercept a moving ball with his/her head. The ball was approaching along a rectilinear path that crossed the actor's axis of displacement (Fig. 1A). In this kind of task, a very efficient strategy consisting in keeping constant the bearing angle between the ball's current position and one's current displacement direction (Fig. 1A) has been noted in past studies [4,9]. Several perceptual variables can be used to determine the bearing angle. The bearing angle is available if the subject relates the ball's current position to the structure of the global flow field, and more precisely, to the focus of expansion (flow variable) (Fig. 1B). The bearing angle is also available if the subject relates the ball's current position to his/her body midline. This kind of egocentric directional coding can be achieved on the basis of visual signals (visual variables) or extra-retinal signals (proprioceptive variables). For example, an environment that provides strong visual references to the locomotor axis allows the subject to perceive the ball's visual egocentric direction (Fig. 1C). On the other hand, in any environment, an easy way to make use of the bearing-angle strategy based on the (proprioceptive) egocentric direction is to anchor one's gaze on the ball and cancel any gaze rotation by modifying displacement velocity accordingly (Fig. 1D).

In a previous experiment, Chardenon et al. [2] showed that changes in displacement velocity depended on a linear combination of visual and flow variables, but also that subjects relied more heavily on visual variables than on flow variables. Once again, these results demonstrate that several perceptual variables are used simultaneously in the control process; they also call for a few comments. First of all, this analysis failed to take the potential role of proprioceptive variables into account, even though proprioceptive signals have been shown not only to play a role in the control of

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other kinds of goal-directed displacement [19,20], but also, unlike both flow and visual variables, to be available in all experimental conditions. For example, if the task is performed in the dark with only the ball visible, the bearing angle can still be determined from proprioceptive variables. In order to get a more realistic view of the underlying perceptual-motor mechanisms involved in this kind of task, the present experiment took the possible role of the three types of perceptual variables into account (Eq. (1)).

$$\ddot{Y} = k_1\mathrm{FV} + k_2\mathrm{VV} + k_3\mathrm{PV} \quad (1)$$

where $\ddot{Y}$ is subject's acceleration; FV: flow variables; VV: visual variables; and PV: proprioceptive variables (these variables specify the bearing angle ϕ (Fig. 1)); k_1, k_2, and k_3: constants.

Secondly, the Chardenon et al. [2] study was conducted in a single environment made up of both the moving ball and a ground plane rendered visible by a structured line grid. It is highly probable that this kind of environment favoured the use of visual variables, which makes it unclear whether the relative dominance of visual variables reflects a general principle underlying the perceptual-motor organisation (also see

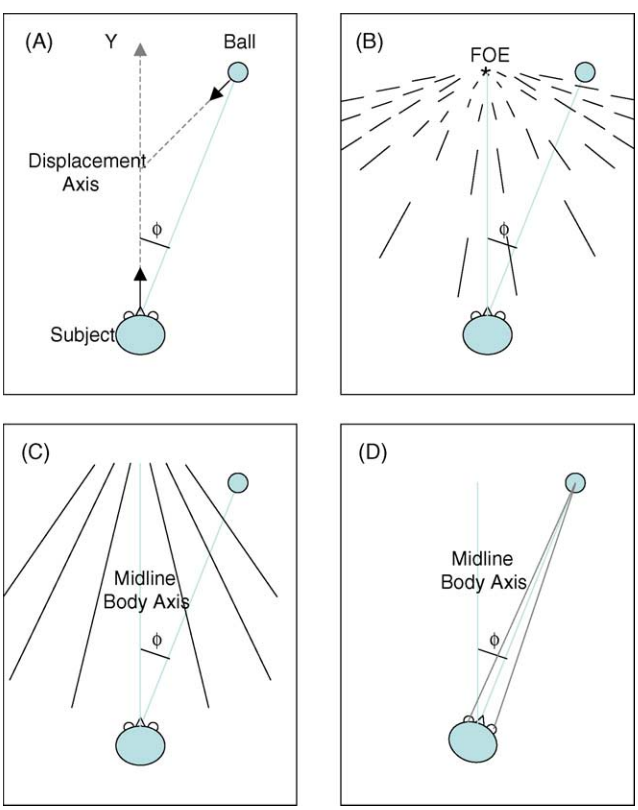

Fig. 1. Interception task utilised in this study (A) and perceptual variables used to determine the bearing angle ϕ (B–D). (A) The subjects had to intercept a ball with their head when it crossed their axis of displacement. (B) Flow variable: the position of the ball is related to the focus of expansion (*). (C) Visual variable: the position of the ball is related to the midline body axis available in visual references. (D) Proprioceptive variable: the position of the ball is related to the midline body axis on the basis of proprioceptive signals.

reference [17]), or a strictly context-dependent organisation. To answer this question, we also manipulated the environment available to subjects as they performed the task.

Nine right-handed subjects participated in the experiment after giving their written informed consent. All had normal vision but varied as to their experience in ball sports. A local ethics committee approved the experimental protocol. The experimental set-up consisted of a virtual environment [5] (consisting of 2 PC Dell Workstations plus an Electrohome 7500 video projector) coupled with an analogical joystick (Happ controls) that allowed participants to control their displacement velocity in the virtual environment. This kind of set-up allows for the precise experimental control of stimuli [16,18]. Note that the displacement velocity was constrained within a fixed range whose minimum value was 0.6 m s^{-1} and whose maximum value was 1.8 m s^{-1}. The visual scene was displayed on a projection screen placed 0.70 m in front of the subject (providing a 118° × 130° visual field) and was continuously changed at an average rate of 60 frames/s, in accordance with the participant's actions. Subjects were seated so that their body midline axis coincided with the ball's axis of displacement (Fig. 1). With this set-up, the visual consequences of a change in displacement velocity were available within 60 ms.

Subjects could freely modify their forward velocity, if necessary, to intercept a virtual ball with their head. The ball was moving at eye level along a straight path that crossed the subject's displacement axis. The ball (0.2 m in diameter) approached at a constant velocity (0.8 m s^{-1}) and a constant angle of approach relative to the axis of displacement (45°), giving rise to a flight time of 8 s. A trial was deemed successful when the ball passed 15 cm or less from the centre of the head, and qualitative feedback was provided after each trial. For each trial, the subject's initial velocity was set at 1.2 m s^{-1} for the first second.

We manipulated the kind of environment available (three environment conditions) and the ball's offset distance (three offset conditions). In the poor environment condition, only the ball was visible, so only proprioceptive variables specified the bearing angle. In the other environment conditions, a textured ground was added. In the semi-rich environment condition, the ground plane was textured (extensionless, randomly distributed dots with 33 dots/m^2), giving rise to a global flow field. Both proprioceptive and flow variables were available in this condition. In the rich environment condition, the ground plane was visible as a structured line grid (0.5 lines/m). This environment condition provided all three perceptual variables, namely, proprioceptive, visual, and flow.

Three different starting positions were used to vary the ball-offset distance in depth (1.5, 0.2, and −1.5 m). If the participant continued at the initial velocity, the ball would pass 1.5 or 0.2 m in front, or 1.5 m behind him/her. As a result the participants had to accelerate (1.5 or 0.2 m) or decelerate (−1.5 m) to succeed. All participants performed eight trials under each of the nine control conditions (3 offsets × 3 environments). The 72 control trials were mixed with