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The visual control of bicycle steering: The effects of speed and path width

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ABSTRACT

Although cycling is a widespread form of transportation, little is known about the visual behaviour of bicycle users. This study examined whether the visual behaviour of cyclists can be explained by the two-level model of steering described for car driving, and how it is influenced by cycling speed and lane width. In addition, this study investigated whether travel fixations, described during walking, can also be found during a cycling task. Twelve adult participants were asked to cycle three 15 m long cycling lanes of 10, 25 and 40 cm wide at three different self-selected speeds (i.e., slow, preferred and fast). Participants' gaze behaviour was recorded at 50 Hz using a head mounted eye tracker and the resulting scene video with overlay gaze cursor was analysed frame by frame. Four types of fixations were distinguished: (1) travel fixations, (2) fixations inside the cycling lane (path), (3) fixations to the final metre of the lane (goal), and (4) fixations outside of the cycling lane (external). Participants were found to mainly watch the path (41%) and goal (40%) region while very few travel fixations were made (<5%). Instead of travel fixations, an OptoKinetic Nystagmus was revealed when looking at the near path. Large variability between subjects in fixation location suggests that different strategies were used. Wider lanes resulted in a shift of gaze towards the end of the lane and to external regions, whereas higher cycling speeds resulted in a more distant gaze behaviour and more travel fixations. To conclude, the two-level model of steering as described for car driving is not fully in line with our findings during cycling, but the assumption that both the near and the far region is necessary for efficient steering seems valid. A new model for visual behaviour during goal directed locomotion is presented.

1. Introduction

Goal directed locomotion is usually guided by information from task specific visual search patterns (Ballard and Hayhoe, 2010). Both in car driving and walking, eye movements have been studied to understand how humans use vision for obstacle avoidance and safe navigation (Marigold et al., 2007; Patla and Greig, 2006; Hildreth et al., 2000; Mourant and Rockwell, 1972; Underwood et al., 2003; Falkmer and Gregersen, 2005). Unfortunately, despite the fact that cycling is a wide-spread form of transportation and is often recommended as a healthy and economic way to do so (Rabl and de Nazelle, 2012), little is known about the visual behaviour of cyclists. With increased use of bicycles for transportation, the number of bicycle accidents also increased (Juhra et al., 2012). Therefore, greater insight in the visual behaviour of cyclists is essential for effective traffic education and infrastructural planning.

In car driving, gaze behaviour can be best described by the two-level model of steering (Donges, 1978; Land and Horwood 1995). According to this model, two visual regions are used for efficient steering. First, a distant point on the travel path is used for controlling heading. On a straight road this is usually the vanishing point, a leading car or a point to which the car has to be steered (Salvucci and Gray, 2004; Land and Lee, 1994). On curved roads, the 'tangent point' has been identified as an important visual cue. This is the point on the inside edge of the bend which protrudes the most in the road and has been shown to be closely linked to the drivers steering behaviour (Land and Lee, 1994; Mars, 2008; Kandil et al., 2009). The second region described in the two-level model is the near road region. This region includes the road and its markings in the immediate proximity of the car and plays an important role for lane keeping. However, this near region is rarely fixated. Instead of switching gaze from far road to near road regions, car drivers tend to fixate mainly the far road and attend to the near road peripherally for position-in-lane feedback. This gaze strategy has been shown to be efficient for multiple steering tasks, such as corrective steering, lane changing and curve negotiation (Salvucci and Gray, 2004).

The two-level model has not yet been explicitly tested for walking but some studies in real-world scene perception also use the distinction between near and far regions (Foulsham et al., 2011; Pelz and Rothkopf, 2007). In contrast to car driving, the near path

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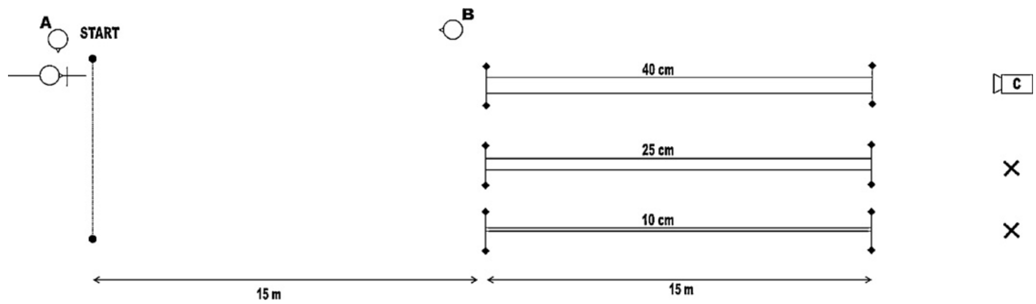

Fig. 1. Experimental set-up. (A) Test leader that gives instructions to the participant; (B) test leader with clapperboard; (C) and (X) places of overview camera.

region is frequently gazed at during walking (±30% of the time) and only few fixations (<10%) are made to the distant path (Foulsham et al., 2011). On an uneven pathway, proportion of gaze to the near path even increases up to 75% (Pelz and Rothkopf, 2007). This 'path-watching' phenomenon can be explained by pedestrians being more dependent on path quality for maintaining dynamic balance, in contrast to car drivers. The fact that pedestrians also spend more time looking at regions irrelevant for the control of locomotion, such as the scenery (Turano et al., 2003), is probably due to the lower speeds at which they travel. At lower speeds, more time is available to anticipate and react to possible hazards, which leads to a lower task demand.

Patla and Vickers (2003) mentioned a specific type of near path fixation during walking, called the travel fixation. A travel fixation occurs when gaze is held on a fixed distance about two steps in front of the body and is carried along at the speed of locomotion. As a result, the point of regard moves at the same speed as the body. During this type of fixation optic flow lines pass through central as well as peripheral vision and are used to obtain information about the self-motion. However, generalization of travel fixations to other forms of locomotion can be questioned since only few other studies described their use (Fowler and Sherk, 2003; Hollands et al., 2002). In addition, the use of travel fixations would mean that the OptoKinetic Reflex (OKR) is suppressed. This OKR is a reflexive eye movement that stabilizes the retinal image by adapting the eye movement velocity to that of the retinal image (Lappe and Hoffman, 2000; Miles, 1998). When moving forward at a constant speed, the environment is perceived as a constant radial optic flow. Without eye movements adapted to the speed of the optic flow, visual pick-up would be blurry. Therefore, a series of optokinetic eye movements is elicited (Solomon and Cohen, 1992; Lappe et al., 1998; Knapp et al., 2008; Niemann et al., 1999). This series of OKR's is called OptoKinetic Nystagmus (OKN) and has been described during simulated rectilinear self motion in the monkey and humans (Lappe et al., 1998; Niemann et al., 1999) and recently also during car driving (Authié and Mestre, 2011). To our knowledge, however, neither travel fixations nor OKN have been described for cycling.

Visual behaviour for walking and for car driving is different, but in both cases humans seem to rely on a synergy of far and near road information. The first aim of this study is to examine whether the visual behaviour of cyclists can be explained by the two-level model of steering. If this model can be applied to cycling as for driving, cyclists would mainly look at distant points while they maintain centred in the lane by attending the proximal pathway peripherally. However, Land and Horwood (1995) noted that at lower speeds (<12 m/s) the near-road information is adequate on its own. In addition, Pelz and Rothkopf (2007) showed that when task demands were higher, vision shifted towards the near region. Therefore, the second aim of this experiment was to test the influence of these constraints on gaze behaviour by imposing three cycling speeds and three lane widths (i.e., a smaller path). It was expected that higher cycling speeds and lower task demands would result in a more distant visual behaviour. Finally, the third aim of this study was to investigate whether travel fixations are made or an OKN is elicited when looking at the path during a in situ linear cycling task.

2. Materials and methods

2.1. Subjects

A convenience sample of nineteen participants took part in the experiment and were recruited from Ghent University's students and staff. Twelve participants aged 21–28 (five females) whose tracking ratio of eye movements (i.e., the time that direction of gaze could be determined/duration of trial) was at least 85% and for whom pre and post calibration were good, were selected for further analysis. All participants had normal or corrected-to-normal vision and all used their bicycle on regular basis for transportation.

2.2. Apparatus

Eye movements were recorded using the IviewX Head mounted Eye tracking Device (SMI, Teltow GER). An infra red *eye camera* was mounted on a baseball cap and recorded the left eye movements at 50 Hz using pupil position and corneal reflex. A *scene camera* with 3.6 mm lens, placed next to the eye camera recorded video images at 25 Hz with a horizontal and vertical field of view of approximately 33°. Both cameras were connected to a notebook which was worn in a backpack. Video and eye tracking data were combined using SMI's software BeGaze 3.0. The system has a spatial accuracy of 1°.

2.3. Set up and procedure

The experimental set up is shown in Fig. 1. Cycling lanes of 10 cm (narrow), 25 cm (middle) and 40 cm (wide) of width and 15 m of length were marked on the floor with a white tape. Two mechanical gates at the start and at the end of the lane gave a visual signal when the cyclist passed through. A line marked the start of the 15 m run-up before the first gate and an *overview camera* (25 Hz, Full HD) stood 4 m behind the second gate to record the cyclist and the signals of the mechanical gates. After calibration, participants were given one familiarization trial for each lane. Subsequently, the test leader (A on Fig. 1) asked the participant to cycle through one of the lanes at self-selected low, preferred or high speed without crossing the edge lines. A start signal was given to the cyclist by a second test leader (B on Fig. 1) using a clapperboard. This signal was also used for synchronizing eye tracking data with the video images of the overview camera. Nine conditions (3 lanes × 3 speeds) were carried out in a randomized order. After the last condition a calibration check was done. All tests were done in a gymnasium with a parquet floor and with a standard city bicycle (women's model) rented from the university bicycle service. Saddle height was adjusted for each