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Primary or secondary tasks? Dual-task interference between cyclist hazard perception and cadence control using cross-modal sensory aids with rider assistance bike computers

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ABSTRACT

This research investigated the risks involved in bicycle riding while using various sensory modalities to deliver training information. To understand the risks associated with using bike computers, this study evaluated hazard perception performance through lab-based simulations of authentic riding conditions. Analysing hazard sensitivity (d') of signal detection theory, the rider's response time, and eye glances provided insights into the risks of using bike computers. In this study, 30 participants were tested with eight hazard perception tasks while they maintained a cadence of 60 ± 5 RPM and used bike computers with different sensory displays, namely visual, auditory, and tactile feedback signals. The results indicated that synchronously using different sense organs to receive cadence feedback significantly affects hazard perception performance; direct visual information leads to the worst rider distraction, with a mean sensitivity to hazards (d') of −1.03. For systems with multiple interacting sensory aids, auditory aids were found to result in the greatest reduction in sensitivity to hazards (d' mean = −0.57), whereas tactile sensory aids reduced the degree of rider distraction (d' mean = −0.23). Our work complements existing work in this domain by advancing the understanding of how to design devices that deliver information subtly, thereby preventing disruption of a rider's perception of road hazards.

1. Introduction

Cyclists can monitor their heart rate and control their cadence, both of which directly affect muscle oxygenation efficiency (Lefever et al., 2014; Zorgati et al., 2013), with bike computers. Bike computers are designed to convey training information by using multiple sensory aids (e.g., visual display, audio alerting, or vibration through handlebars (Gibbs, 2013). However, the attention capacity of each individual is limited (Scharff et al., 2011), and using a bike computer can either attenuate rider visual attention to riding tasks, such as observing hazards (Cullen et al., 2013), or enable riders to optimise their distribution of resources (Talsma et al., 2010). Given that cyclists today can reach average speeds of 40–60 kph without any electronic safety systems, such as an Antilock Braking System, this type of distraction entails a serious risk of injury or death. Therefore, in this research, we studied the degree of visual distraction by perceptual modalities used in a cadence feedback computer.

To interact with a device, riders must divide their attention in ways that are, as yet, poorly understood. As shown in Fig. 1, switching voluntary attention between road hazards and cadence control with bike computer assistance could cause the rider to suspend the attention paid to one of these (Preece et al., 1994). Especially in some cases (Al-Yahya et al., 2009; Simoni et al., 2013; Venema et al., 2013), human locomotor movements significantly decrease cognitive performance.

In the case of a rider using a bike computer, the rider is executing primary (ongoing) tasks, such as perceiving hazards and balancing the bike, and secondary (interrupting) tasks, such as maintaining a cadence. Information from a bike computer provides guidance for choices and actions; in this situation, secondary tasks often attract the most attention (Lu et al., 2011). Although widespread usage of bike computers has affected riding behaviours, research discussing optimal sensors and sensory integration for bike computers remains scarce.

The integration of multisensory data can improve one's perception of coherent perceptual entities (Lewkowicz and Ghazanfar, 2009; Meredith et al., 1987). Researchers, such as Shams et al. (2000), have argued that visual perception can be

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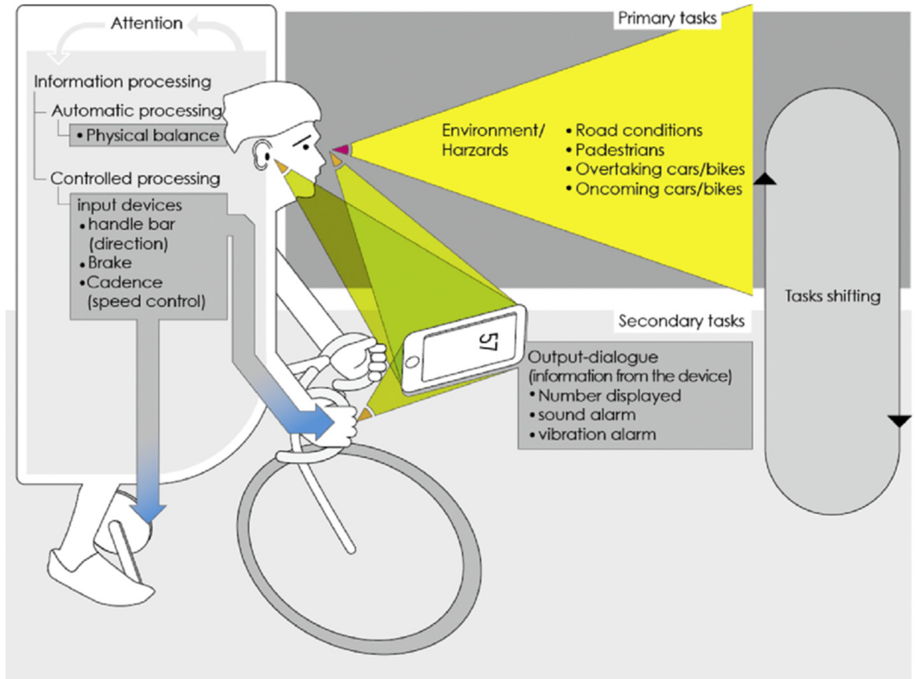

Fig. 1. Task-information processing in cycling with bike computer.

manipulated by other sensory modalities. Bike computers generally include navigation systems similar to physiological monitoring systems, in which current information system interfaces come in several forms, including a (1) visual display, (2) audio reminder, (3) tactile reminder, and (4) multisensory interface (e.g., visual and audio). The bicycle-specific scenario is one in which the bicycle's stability can be suddenly degraded in unexpected situations or when the bicyclist is distracted (Dozza and Werneke, 2014).

Effective performance depends on whether two or more tasks compete for one resource (Wickens, 2008). We investigated how to deliver information effectively with the least disturbance to observation activities. Specifically, we sought to answer the following questions:

RQ1: How does the information delivery of a bike computer affect how a rider primarily detects oncoming hazards?

RQ2: How does an alternative information delivery mode (auditory, tactile, or multisensory) affect how a rider primarily detects oncoming hazards?

2. Material and methods

The experiment, consisting of hazard observation tasks requiring constant monitoring and action, as well as a secondary task of consistent pedalling with guidance from a bike computer, simulated numerous road conditions that riders regularly encounter. During their responses to road hazards, the participants were required to maintain their riding cadence at 60 ± 5 RPM as the secondary task. In these dual tasks (Fig. 2), following the rules of the Hazard Perception Test of the U.K. driving license test (DVSA, 2015), the participants were required to press a button fixed on the end of bicycle handlebars (Yang, 2012) when they observed a developing hazard. All the hazard perception clips included 10 occasionally encountered hazards. When the button was pressed, a visible red laser dot marked the video projection screen.

Before the tests were started, there was a warm-up session in which the participants were asked to perform the primary task (responding to hazards) while riding the simulated bicycle and watching a 3-min video clip of a rural area. The primary task served as a control (coded as ND). In all trials, we notified the riders when they first reached the target RPM range. The participants were then asked to respond to hazards by pressing the button and to manage the cadence intuitively; after that, no further information was provided. For the secondary task, cadence control signals were delivered through visual, auditory, tactile, and mixed modes.

2.1. Experimental setup

Referring to the Hazard Perception Test of the U.K. driving license test (DVSA, 2015), the experiments were conducted in a lab environment to limit attentional resources hazard detection tasks. In the lab, the subjects did not need to pay attention to balancing the bike, deciding on directions, or braking. The real-world performance of road bicycles, a type of bicycle highly prone to collisions, was simulated in the experiment. The bicycle was fitted to a Tacx™ Fortius Multiplayer T1930 virtual reality trainer by using Tacx 2.0 (T1990.02) software. The road environment was projected at a 4:3 ratio on a 95.5-in screen positioned 170 cm in front of the test subject's eyes. A Garmin® Edge705 bike computer was fitted to the centre of the bicycle handlebars. The steering was disconnected from the control of the simulated riding scene to ensure that participants were not distracted by controlling their riding routes or avoiding hazards.

2.2. Experimental stimuli

2.2.1. Road hazards

Hazard perception clips consist of computer-generated imagery shown from the perspective of a cyclist by Tacx™. Accidents are mostly the result of a rider being unable to process environmental information in a timely manner. In this study, as in driving studies, front event detection was designed to be sensitive to the behaviours of both handheld and hands-free phone users (Victor