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Comparison of two warning concepts of an intelligent Curve Warning system for motorcyclists in a simulator study

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ABSTRACT

Curve crashes are a particular matter of concern regarding motorcycle riding safety. For this reason, an intelligent Curve Warning system has been designed that gives the riders support when negotiating a curve. The system has been tested in a simulator study carried out with 20 test riders. The subjects performed three rides: one without the system (baseline) and two experimental rides using a version of the Curve Warning system, one providing the warnings by a force feedback throttle and one by a haptic glove. The effects of the two system versions were evaluated both in terms of the simulated riding performance and the subjective assessment by the riders. A descriptive analysis of the riders' reactions to the warnings shows that the warnings provided by both system versions provoke an earlier and stronger adaptation of the motorcycle dynamics to the curve than when the riders do not use the system. Riding with the Curve Warning system with the haptic glove furthermore leads to a reduction of critical curve events. The riders' subjective workload level was not affected by the system use, whereas the Curve Warning system with the force feedback throttle required an increased attention. The comparison of the riders' opinions about the system reveals a preference of the Curve Warning system with the haptic glove. The better acceptance of this system version suggests a higher potential in the enhancement of riding safety.

1. Introduction

The growing popularity of motorcycle riding is mirrored in the increasing number of motorcycles registered in the European Union. From 16 million motorcycles in 2001, the number has risen up to more than 22 million in 2008 (ACEM, 2010). At the same time, recent accident studies show that motorcycle riding safety is still a relevant matter of concern (e.g., ETSC, 2003; NHTSA, 2006; SafetyNet, 2008). Motorcycle riders are not only more at risk of suffering an accident than car drivers; they are also much more vulnerable due to their lack of protection. Compared to driving a car, riding a motorcycle implies an 18 times higher mileage-related risk of being killed in a crash, with 5126 motorcycle fatalities registered in the European accident data base CARE (Community database on road accidents) for 24 member states of the European Union in 2008 (DEKRA, 2010). While overall road fatalities have successfully been reduced in the decade from 2000 to 2009, many European countries have suffered an opposite trend in fatal motorcycle crashes (IRTAD, 2010).

The types of crashes which usually involve motorcycle riders differ from the crash configurations of other road users. The most prominent scenario is the single-vehicle motorcycle crash outside urbanized areas, where the rider runs off the road at a relatively high speed, representing up to 27% of all motorcycle crashes (Hurt et al., 1981; MAIDS, 2004; TRACE, 2008). Furthermore, these crashes are generally more severe than other motorcycle crashes, with a doubled fatality risk and an only slightly lower increase in the probability of serious injuries (Clarke et al., 2004).

Riding a motorcycle differs in many ways from driving a car, especially regarding the higher levels of motor-skills, physical coordination and balance required from the rider (Mannering and Grodsky, 1995). Therefore, the riding safety is particularly sensitive to errors committed by the rider. In almost 90% of all motorcycle crashes human error is a causal factor and in approximately 37% of the crashes the crash is provoked by a rider error, most frequently attentional failures or inadequate choice of behaviour (MAIDS, 2004). As stated by Di Stasi et al. (2009), the rider's awareness of the road situation and the corresponding judgement on

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appropriate riding manoeuvres are crucial factors for riding quality and the consequent risk of having an accident. One of the riding behaviours which has proven to increase crash probability is riding at an unsafe speed (Fildes et al., 1991; Maycock et al., 1998; Lin et al., 2003; Wells, 1986).

Motorcycle riding usually satisfies "extra motives", a motivational concept referring to the use of the vehicle for enjoyment rather than for the satisfaction of mobility needs, where the purpose of the trip is the riding experience itself (Broughton et al., 2009; Summala, 1988). Due to their higher manoeuvrability, motorcycles provide the riders with the opportunity to use their vehicle in an expressive way, allowing for a more intense user experience (Broughton, 2005; Jamson, 2004; Mannering and Grodsky, 1995; Sexton et al., 2004). On the other hand, this leads to an increased vulnerability to lose control of the motorcycle, which is enhanced by the choice of high speed for an enjoyable riding experience (Broughton et al., 2009; Moller and Gregersen, 2008).

Regarding curve crashes, Hurt et al. (1981) identified "slide-out and fall due to overbraking or running wide of a curve due to excess speed" (p. 416) as common rider errors. Accordingly, Clarke et al. (2004) found that most single vehicle crashes were caused by the rider's misjudgement of the appropriate speed when riding through a curve, and that the majority of the riders are aware of this error. The authors concluded that countermeasures must address the need to make riders slow down in relation to road hazards like bends. However, there is still a lack of knowledge on how the human factor can be influenced in order to enhance riding safety (Elliott et al., 2007).

A system that alerts the rider that he or she is approaching a curve at an unsafe speed could provide valuable support. However, the effectiveness of the system will greatly depend on the riders' acceptance and use of the system. The purpose of this study is therefore to examine motorcycle riders' use of a Curve Warning system in a riding simulator. Two warning concepts using different rider interfaces are examined and compared to baseline riding for performance around curves, opinions of system functionality and interface, and overall acceptance.

2. The Curve Warning system

In accordance with the identified need to support riders in safely negotiating curves, the Curve Warning (CW) system has been designed to detect incorrect, insufficient or missing rider actions with regard to the longitudinal control of the vehicle when approaching a curve. It aims at warning the rider discreetly but effectively in case of detected risk (Biral et al., 2010). At a frequency of 5–10 cycles per seconds, the CW function calculates a safe reference manoeuvre for riding through the curve ahead. Therefore, it predicts speed and roll patterns by processing digital maps, GPS information and inertial measurements.

The CW function is an instantiation of advanced holistic techniques of non-linear optimal control that accounts for many aspects of the motorcycle dynamics and scenario characteristics. More in detail, the safe-optimal preview manoeuvre is calculated by complying with physical laws of vehicle dynamics, road constraints, riding comfort and safety. Always giving priority to the satisfaction of these requirements, the system computes the fastest possible reference manoeuvre, accounting for speed as a major riding motive (Biral et al., 2010). The computed reference manoeuvre is constantly compared with the actual riding parameters. In that way, the system identifies the risk level of the present riding situation and emits a warning only in case this level reaches a threshold. Thus, the criterion for providing the rider with an alert is not merely a potential danger identified by the system (i.e. a sharp curve ahead), but the mismatch between the rider's behaviour when approaching the curve and the necessary manoeuvre calculated by the system. The system's preview horizon of 200 m facilitates the early detection of potential risks, corresponding to 5 s at a riding speed of 140 km/h. The warning can be transmitted up to 2 s before reaching the curve, a sufficient time margin for the rider to react safely. On the other hand, in a reference scenario where the rider is approaching the critical location and shows an appropriate adaptation of the riding behaviour, no warning will be emitted. This real-time check allows providing warnings only in situations where the rider does not seem to be aware of the risk he or she is taking and, consequently, unnecessary annoyance or distraction of the rider by a redundant message is avoided.

The CW system is combined with two alternative rider interfaces: a force feedback throttle (th) and a haptic glove (hg). In the first setup, the alert is transmitted to the rider through a force feedback applied on the gas-throttle handle (Fig. 1a). If the rider's speed is too high, the stiffness of the throttle increases. In this warning concept, the alert is congruent with the desired reaction. In fact, the force feedback implies a suggestion to the rider to slow down. The selection of the desired reaction should therefore be more intuitive to the rider. On the other hand, this kind of warning is of intrusive character, since it affects a component of the vehicle control. Therefore, special attention has to be paid to its possible effects on the riding behaviour and the acceptance by the motorcyclist.

In the second setup, the right glove transmits the warning signal by vibration applied to the rider's wrist (Fig. 1b). On the left hand the rider wears a traditional motorcycle glove, while the glove providing the warning signal is equipped with electronics and vibration motors. Contrary to the force feedback throttle, this warning strategy is independent from the vehicle controls and has no relation to speed. The rider does not receive a direct intervention and has to deduce that a vibration on the wrist alerts him of unsafely high speed.

In addition to the interface transmitting the alert, the system status is shown on a visual display mounted on the handlebar. The Curve Warning icon that changes its colour according to the system status has an informative character and is not intended to direct the attention of the rider as a part of the warning strategy.

3. Methods

3.1. Participants

A total of $N = 20$ riders participated in the experiment on a voluntary and unremunerated basis (19 males and one female). The participants' age ranged from 21 to 30 years (mean $M = 25$, standard deviation $SD = 3.20$). The total riding experience varied considerably among participants, ranging from 800 km to 200,000 km, and the current use of the motorcycle varied from 300 km ridden during the last year up to 20,000 km ridden in that period. The majority of the test riders indicated "fun" as their principal riding motive ($n = 14$), while "commuting or mobility needs" were chosen by $n = 6$ participants.

3.2. The DIMEG riding simulator

The experiment was carried out in the riding simulator (Fig. 2) at the Department of Innovation in Mechanics and Management (DIMEG) of the University of Padova (Italy), where the Curve Warning system has been implemented. The simulator is composed of an instrumented motorcycle mock-up, software for the simulation of the motorcycle dynamics and three subsystems for the motion, visual and acoustic cues. All these components have been integrated into a virtual traffic environment where the rider may