Applied Ergonomics 45 (2014) 734–740

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

Towards identifying the roll motion parameters of a motorcycle simulator

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ARTICLE INFO

Article history:
Received 26 July 2012
Accepted 17 September 2013

Keywords:
Driving simulation
Simulator fidelity
Field of view

ABSTRACT

This study aimed at identifying the roll motion parameters of a motorcycle simulator prototype. Experienced motorcyclists tuned the angular physical movement of the mock-up and that of the visual scene to achieve an optimal riding experience during curves. The participants exceeded the rolling angles that would be required in real-world riding, while avoiding leaning the mock-up beyond 10°. In addition, they were more influenced by the speed of the virtual motorcycle than by road curvature, especially in a wide field of view. Heterogeneity was found in the roll applied to the visual scene. The overall patterns suggest that at least when washout is not applied to remove the side forces that in real-world riding are compensated by a centrifugal force, greater roll of the visual at the expense of the mock-up is mandatory to avoid performance biases that might be enhanced due to fear of falling off the simulator. Future roll motion models must take into consideration factors such as riding postures, which might not only influence the forces operating on the rider-motorcycle system, but also how motorcyclists perceive the visual world.

1. Introduction

The application in recent years of motorcycle simulators to study motorcycle riding skills (e.g., Crundall et al., 2012; Crundall et al., 2013; Di Stasi et al., 2009; Di Stasi et al., 2011; Hosking et al., 2010; Liu et al., 2009; Shahar et al., 2010) has the potential to contribute to the development of rider skill and safety.

Although low fidelity driving simulators can be effective tools for assessing various issues, simulators that do not incorporate motion capabilities are more limited and their use to study certain matters may well be inappropriate. Vestibular and somatosensory motion cues have a beneficial effect on driver behavior in sensorimotor tasks such as braking (e.g., Malaterre and Fréchaux, 2001) and lateral trajectory control (McLane and Wierwille, 1975). When riding a motorcycle however, roll is actually being used to control trajectory. Indeed, researchers in the area of motorcycle safety are motivated to develop motion-based motorcycle simulators and to apply them toward studying motorcycling performance, especially in tasks such as curve negotiation, where the use of static simulators seems to be less appropriate (e.g., Crundall et al., 2012).

However, the benefits of motion cues might be outweighed by adverse effects if false forces and cues are generated, or when poor coupling between inertial and visual cues is achieved (Pinto et al., 2008). Studies looking into the coupling between visual and inertial cues typically aim to characterize the proportions between the movements of the base of the simulator and of the visual scene. Such investigation has been undertaken in the context of flight simulation for angular movements (e.g., Reid and Nahon, 1985; Van der Steen, 1998) and in driving simulation with longitudinal movements (e.g., Filliard, 2009; Neimer and Mohellebi, 2009) as well as in a tilt-coordination task (e.g., Groen and Bles, 2004).

This study was concerned with the coupling between visual and inertial cues in a motorcycle simulator. To date, there have been only very few studies working toward these ends (Cossalter et al., 2010; Kageyama and Tagani, 2002; Stedmon et al., 2009).

All motion-base simulators including driving, riding and flight simulators have a limited range of movement due to restricted actuators. Flight roll has the same basic dynamics as motorcycle roll. Absolute roll angles of motorcycles are never rendered not only due to these physical limits, but because doing so introduces lateral and a gravity forces that in real riding are balanced by a centrifugal force, which allows the motorcyclist to maintain balance. In more detail, in order to pass through curves, real motorcycles must reach lean angles (hereafter, theoretical lean angles) that correspond to

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0003-6870/$ – see front matter
http://dx.doi.org/10.1016/j.apergo.2013.09.013

both their linear speed and their trajectory's curvature (which is typically nearly identical to the road curvature). For a given curvature, greater speeds require more extreme lean angles. Similarly, for a given speed, larger curvatures, hence, tighter curves require more extreme lean angles. When leaning a real motorcycle, the continuous forces, mainly gravity "pulling" the rider toward the ground, are compensated during the steady state part of the curve by a centrifugal force. Consequently, there are virtually no lateral forces operating on the rider.

One manner to cope with the false side forces generated when tilting a motorcycle mock-up is delivering most of the tilt sensation by rolling the visual scene (e.g., Cossalter et al., 2010). In flight simulators high-pass filters are used so that the roll cue is generated without a continuous lateral force false cue. However, the pilot seats in a sealed cab, whereas on motorcycle simulators the rider can see the floor. Importantly, the proximity to the ground when leaning a motorcycle might actually be an important component in the motorcycling experience, one that is lost when the roll is delivered through the visual. Moreover, there are a few other substantial differences between steering and angular movements of an aircraft and a motorcycle, such as the manner by which the posture adapted by a motorcyclist when negotiating curves can affect the coordinated motion of the motorcycle/rider system, suggesting that knowledge from aircraft simulation needs be implemented in motorcycle simulators with some caution.

Kageyama and Tagani (2002) have examined the relationship between the physical movement of the simulator on the roll axis and the roll motion of the visual scene (hereafter, physical roll and visual roll) associated with a credible illusion of roll among motorcyclists. They successfully reproduced the most realistic illusion when the scale factor for the motorcycle mock-up was twice as large as compared to the visual scene. These findings however are based on a sample of only four participants. In Cossalter et al. (2010), the opposite pattern was found, that is, the most realistic riding feeling was reported when the roll of the visual scene was proportionally larger than that of the mock-up of the motorcycle.

Stedmon et al. (2009) compared conditions where the visual scene has been rolled in the opposite direction from that of the motorcycle roll movement on the same axis and conditions where it remained horizontal. While both of these conditions resulted in similar riding performance, 10 of 16 riders preferred the configuration where the visual scene was rolled, 2 preferred the configuration where it was not rolled, whereas 4 participants had no preference. Although rolling the visual scene in the opposite direction from that of the motorcycle roll movement on the same axis seems to comply with geometric principles if the motorcyclist's head is perfectly aligned with his or her body and with the motorcycle when leaning into the bend, motorcyclists often keep their head upright, thereby keeping their eyes parallel to the road. In the context of an aircraft simulator, it has been found that visually induced roll sensation is influenced by head orientation (Young et al., 1975). On a motorcycle, the proximity to the road surface and the exact point of fixation might both operate as moderating factors, which further influence the illusion of a rolled visual scene. In this regard, it is quite likely that both the direction of the roll and its amplitude (roll angle) are dependent on the riding posture and on the visual strategies.

In the current study, experienced riders were required to tune the visual and physical roll motions to achieve a realistic sensation of leaning, that is, similar to real-world riding, for a variety of theoretical lean angles and road curvatures. They thus received a greater level of freedom than in previous studies, where participants had to judge pre-determined gains. As such, this study would a), provide useful insight on motorcyclists' own preferential coupling between the physical and the visual rolls and b), allow examining whether indeed motorcyclists have a clear preference for a visual scene that is rolled in the opposite direction of the bend. Selecting some theoretical lean angles that exceed the limits of our simulator's actuators, would allow further insight into the extent to which experienced motorcyclists might be willing to accept visual angular roll to compensate for the limited physical angular roll.

Because theoretical lean angles correspond to both speed and trajectory (i.e., curvature), in order to create the independent variable 'theoretical lean angles' for the chosen curvatures (the second independent variable), the participants performed their task while the virtual motorcycle's trajectory and speed had been both computerized and automated. Thus, the chosen radii of curvatures were coupled with appropriate speeds, to produce the chosen theoretical lean angles. Thus, the participants sat on the simulator, while tuning the physical and visual roll motions so that these would best match the virtual motorcycle's trajectory and speed that they were experiencing and that they did not control. The magnitudes of the roll motions applied by the participants were compared to the theoretical lean angles for the variety of riding conditions. We assessed the extent to which these roll motions deviate from what might be expected (i.e., the theoretical angles), and we discuss the possible reasons for this.

Finally, the current study aimed to further explore the effects of the size of the visual display and of the visual angle (the third independent variable) on the rendering model. Based on evidence demonstrating that speed is perceived to be faster when visual information is presented on a wide- than on a narrow-display (e.g., Alfano and Michel, 1990; Jamson, 2000; Pretto et al., 2009; Toet et al., 2007) and because for a given curvature higher speeds require more radical lean angles, one might expect that the participants would reach greater overall rolls for the same riding conditions (i.e., linear speeds and curve characteristics), when these are presented on a wide- as compared to a narrow-display.

2. Method

2.1. Design

A $3 \times 2 \times 2$ within subjects design was employed with three theoretical lean angles (10°, 20° and 30°), two road curvatures (150 and 300 m) and two conditions of field of view (narrow and wide). Specifically, the visual representation of the riding conditions with respect to the radii of curvatures and approaching speeds was such that if occurred on a real road the rider would have had to lean the motorcycle by 10°, 20°, or 30° in order to pass safely through the bend. Thus, given the theoretical lean angles and the radii of curvatures chosen, six passing speeds were obtained (see Table 1), of which each two corresponds to the three theoretical angles per each of the curvatures. The participants underwent the same type of task twice, once with a narrow field of view (FoV) and once with a wide FoV.

For each of the FoV conditions, the test consisted of one block per each of the six sub-conditions created by the theoretical lean

Table 1
Speeds of the virtual motorcycle (km/h) are given as a function of the theoretical lean angles and radii of curvatures. Speeds were determined on the basis of the following formula: $v = \sqrt{(RC.g.\tan(\varphi))}$, where v is the passing speed, RC the radius of curvature, g the gravity and φ the roll angle of the theoretical lean angle.

Radius of curvature	Theoretical lean angle		
	10 deg	20 deg	30 deg
150 m	58	83	105
300 m	82	118	148