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A comparison of immersive and interactive motorcycle simulator configurations

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ABSTRACT

Two main factors seem to contribute to the development of a riding configuration, and consequently of a motorcycle simulator: the trajectory control modality and the leaning rendering. The goal of this study was to compare two riding simulator configurations through the assessment of the underlying mental workload adopting a multidimensional approach based on psychophysiological, performance, and subjective measures. In the first configuration (*reduced motion*), the trajectory control is obtained by means of positive steering, while the leaning is produced just by tilting the visual scene. Like a real motorbike, the second configuration (*dynamic*) allows a progressive transition between positive and counter steering as the speed increases, whereas the leaning is rendered by splitting the rolling angle between the tilting of the visual scene and the rolling of the platform.

Each participant completed six lane-change tasks per configuration, of which the first three and the last one were single tasks, and the remaining two were dual tasks. The occurrence of three single-task runs at the beginning of the experiment allowed us to examine the process of adaptation to each configuration, which is a critical precondition for simulator validity. The *dynamic* configuration proved to have higher validity, as confirmed by psychophysiological and subjective measures. Findings might have implications for the development of future riding simulators.

1. Introduction

Motorcycles help reducing traffic and parking congestion. However, despite the large number of users, riding a motorcycle is still considered to be a safety hazard. Recent statistics show that while the total number of road deaths is decreasing in European countries, the proportion of motorcycle rider fatalities is rising, together with the number of motorcycles on the road (ONISR, 2010).

The main setting where to study the behavior of this vulnerable group of road users is the simulated environment; however, while driving simulators have been largely used and validated for this purpose (for a review, see Kemeny & Panerai,

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2003; Pinto, Cavallo, & Ohlman, 2008), motorcycle simulators have been rarely employed, and several fidelity and validity issues subsist (Cossalter, Lot, & Rota, 2010; Stedmon et al., 2011). While fidelity generally refers to both the subjective and objective realism of the simulation, validity relies on the correspondence between the simulator and the real world in the way the human operator behaves (Godley, Triggs, & Fildes, 2002; Malaterre & Fréchaux, 2001; Törnros, 1998).

Recently, Sahami and Sayed (2013) argued that when participants start to drive a simulator, they have to learn/observe the simulator outputs to refine their skills and strategies. Consequently, they need time to adapt and transfer their already existing driving skills to the simulator (Sahami & Sayed, 2010). This period of time, called adaptation process, is a crucial critical precondition for validity of experiments carried out using any simulator (Sahami & Sayed, 2013). According to Ronen and Yair (2013), during this period drivers/riders have to transfer motor-cognitive skills that are mainly required to correctly operate the simulator and respond to the simulated environment. These actions impose an extra mental workload on the person, which lasts until driving becomes automatic (Sahami & Sayed, 2013).

In this respect, the goal of this study was to compare different riding simulator configurations, through the assessment of the underlying mental workload. Although a strong link between adaptation and validity has been shown (Ronen & Yair, 2013; Sahami & Sayed, 2013), previous studies concerning riding simulators validation have not explored this crucial phase exhaustively. The literature on driving/riding simulators validation have mainly relied on performance measures such as speed and acceleration (e.g., Cossalter et al., 2010; Godley et al., 2002), braking (e.g., Hoffman, Lee, Brown, & McGehee, 2002), trajectory (Cossalter et al., 2010; Törnros, 1998), road/lane exit and collisions (Stedmon et al., 2011), and subjective measures (Cossalter et al., 2010; Stedmon et al., 2011), without focusing on the adaptation phase. In this study we tried to explore the adaptation process adopting a multidimensional approach based on psychophysiological, performance, and subjective measures (De Waard, 1996; Di Stasi et al., 2009).

From the review of existing interactive riding simulators – whose purpose is to study riders behavior – two main factors seem to contribute to the development of a riding configuration: the visual and inertial leaning rendering, and the modalities for the trajectory control. Concerning the leaning, since in a simulated environment it is physically impossible to reproduce the entire leaning angle of a real motorbike – because of the absence of centrifugal forces – both the tilting of the visual scene (counter-side to the direction of the bend and of the leaning of the motorcycle) and the rolling of the platform should work together to reproduce the leaning rendering. According to Cossalter et al. (2010), appropriate tuning should split the rolling angle into a bigger part, which is operated by the visual output, and a smaller one handled by the platform. As to the trajectory control, in the real world it is made by means of both positive steering at slow speed, i.e. by turning the handlebar toward to the desired direction (steer left to turn left), and counter steering, namely steering counter to the desired direction (steer left to turn right) as the speed increases. To negotiate a turn, the combined center of mass of the rider and the motorcycle must first be leaned in the direction of the turn, and steering briefly in the opposite direction causes the lean. The heavier and faster the motorbike, the more valuable becomes the counter steering since shifting the body weight becomes less effective (Fajans, 1999).

Consistent with Nehaoua, Arioui, and Mammar (2011), three families of riding simulators can be identified within the sparse literature: reduced motion simulators, parallel platform based simulators, and serial platform based simulators. The following is an up-to-date summary of the best-known riding simulators.

The Honda Riding Trainer (HRT) is a low-cost reduced motion motorcycle simulator developed by Honda (Japan), which consists of a tubular chassis, a seat, handlebar, pedals, speed selector, a small screen for the visual output, and software for the simulation of the motorcycle dynamics. Among all the existing motorcycle simulators, it is the most widely used, and has been employed to train and assess riders (Vidotto, Bastianelli, Spoto, Torre, & Sergeys, 2008), to study hazard perception (Liu, Hosking, & Lenné, 2009; Shahar, Poulter, Clarke, & Crundall, 2010), and to assess mental workload (Di Stasi et al., 2009). However, it allows just positive steering, and it reproduces the leaning only by tilting the horizon.

The MotorcycleSim (Stedmon et al., 2011) is a parallel platform based simulator developed by the University of Nottingham (UK), which consists of a fully equipped motorcycle with two pairs of pneumatic actuators that allow leaning, a projection screen, and dedicated software for the simulation of the motorcycle dynamics. However, despite this simulator could theoretically lean to the sides, experimental evidence (Crundall, Crundall, & Stedmon, 2012; Stedmon et al., 2011) showed that no physical bending was allowed as it was used in a static mode with the pneumatic actuators pressurized to stabilise the motorcycle and the rider. The riding experience of leaning into bends was obtained by tilting the horizon, while braking and acceleration effects were simulated by pitching actions in the visual outputs (Crundall et al., 2012). Recent results from Stedmon et al. (2011) showed riders to prefer a tilting horizon rather than a static one. The results also showed that both of these visual output conditions resulted in similar riding performance. Concerning the trajectory control, the simulator allows both positive and counter steering. However, in the current version of MotorcycleSim, the simulator does not allow a progressive transition between slow speed control, where the positive steering is more effective, and increasing speed control, where riders adopt counter steering (Stedmon, Brickell, Hancox, Noble, & Rice, 2012). Experimental comparison of these steering configurations revealed the positive steering to be preferred to the counter steering, together with a higher degree of control with less off road accidents, collisions with other vehicles and time spent out of lane (Stedmon et al., 2011).

The DIMEG simulator, developed by the University of Padova (Italy), is a serial platform based simulator, which consists of a fully instrumented motorcycle mock-up mounted on a cubic cage that supports the frame motion via four steel suspended cables, sensorized handlebar and footpads, software for the simulation of the motorcycle dynamics, and three subsystems for the motion, visual and acoustic cues. This mechanical conception helps reducing frictions and allows a good distribution of the gravity forces. The DIMEG simulator is able to reproduce the counter steering behavior as a response to the rider steering