Subjective Validity of Bicycle Simulators

Bicycle Simulator Study

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***Abstract*— In this paper, we briefly present a subjective experimental validation of the bicycle simulator. In the first part, we present the different physical features of the simulator developed at The Perceptions, Interactions, Behaviors & Simulations Lab for road and street users (PICS-L). In the second part, we present the results of an experiment with 10 participants in order to verify the liability of the simulator. For future work, the authors will deploy the simulator in behavioral studies and compare the outputs with experimentation in real environment seeking for the behavioral validity of the simulator.**

Keywords- Bicycle Simulator; Simulation; Subjective Validity.

I. INTRODUCTION

This article is ongoing study started in [1] aiming at improving the dynamics of the bicycle model and simulations to deploy it in future studies on cyclists' behavior and their interaction with different road features in a safe and controllable environment. While our previous work focused on the dynamical modeling of the bicycle simulator, we focus here on the subjective validity of the simulator.

Studying road-user behavior through simulations is a promising tool to address challenges, such as: learning to drive, awareness of risks, road safety, etc. Different simulators have been developed over the past three decades with different focuses and goals [2]-[4]. We can categorize them into: motionless simulators and mobile-based simulators [5]. The first are built around a screen providing visual feedback as in [7], while the latter combines visual information and indices of movements consistent with those of a real vehicle as in [8]-[10]. It has been recognized that often a mobile platform, if well controlled, can significantly improve the realism of the simulation of conduct.

The PICS-L lab at Université Gustave Eiffel designs and develops simulators of conduct to study the behavior of drivers and vulnerable users (cyclists and pedestrians) in different situations, interactions with other users, and information-gathering strategies, in order to better understand the users' immersion in a virtual reality environment [7].

The intermediate complexity and level of realism of the PICS-L bicycle simulator is ensured through several features on the base and background platform, movement control and through numerous sensory information and measurements. These features aim at allowing the cyclists natural behavior, such as: movements, interactions, integrated sound and visual effects similar to the real environment. This equips the simulator for studying cyclists' interactions with other users, road improvements and driving aids. This allows the assessment of the cyclists' subjective risk, perception of and reaction to the infrastructural environment and other road users, as well as anticipation and decision-making. It is noteworthy to state that aspects of balance management and shock situations had been excluded, therefore deferring the study of situations including loss of control and shock, as well as high dynamic demands.

By considering the cyclist as a control system, we could better understand driver behavior and improve the modeling quality of the bicycle and its simulator. In the following, we will focus on the subjective aspects of the bicycle simulator through analyzing different questionnaires. The design of the experiment aims to verify the reliability of the bicycle simulator to validate the model for future experiments. The paper is organized as following. Section 2 is devoted to present the bicycle modeling. In Section 3, experimentation environment and scenarios are detailed, and the results are presented in the Section 4.

II. BICYCLE MODELING

The bicycle dynamic model was created in MATLAB-Simulink, it shows the relations between the different parts of the bicycle model in a graphical format. This allows to graphically trace the various inputs and visualize their relation in MATLAB script format. The model has different sub-layers showing the relative outputs of the different parts. Fig. 1 presents the input /outputs of the Simulink model [1], which was used in the analysis following the simulation.

Eq. (1) was implemented to estimate the friction force:

$$m.\frac{dv}{dt} = F_F + F_a + F_c + F_B + F_g \tag{1}$$

where m is the total mass of the bicycle-rider system in kg, $\frac{dv}{dt}$ is the longitudinal acceleration as a function of the speed in m/s^2 (the speed was measured using an incremental encoder attached to the rear wheel of the simulator), F_F is the friction force to be calculated, F_c is the force applied by the cyclist on the pedals which is measured using a pedal power meter, F_b is the breaking force and F_g is the gravity force caused by the slopes, F_a is the aerodynamic resistance calculated on the basis of the following equation:

$$F_a = 0.5\, C_{(ax)} \rho\, S\, v_x^2$$

with C_{ax}, the coefficient of aerodynamic resistance given by the bicycle manufacturer, ρ the air density in kg/m^3 and S the frontal surface of the bicycle and the rider body in m^2.

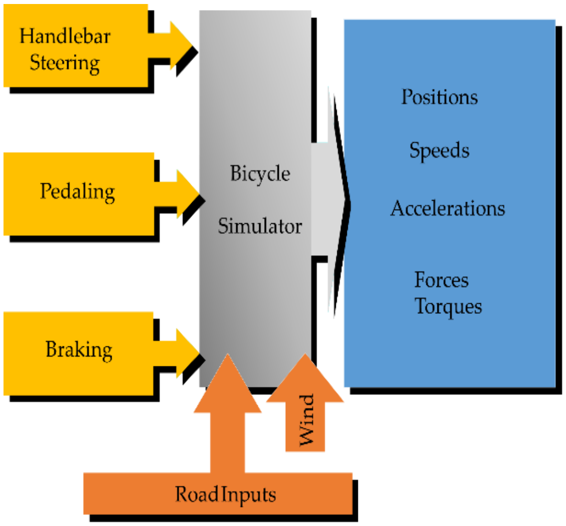


Figure 1. Input/Outputs of the bicycle simulator.

III. EXPERIMENTAL ENVIRONMENT

A. Experimental Setup

The Bicycle Simulator at PICS-L (UGE) with the primary aim to study the bicycle control in virtual environments, was designed by placing a real bicycle on a fixed platform.

The speed of the rear wheel, the angular position of the handlebar, and the gear were measured and logged. A force feedback was applied to the rear wheel using a cylinder in contact with the wheel. The system was composed of a 10N constant part to simulate the dry friction, a variable part to simulate the dynamic friction in proportion to the speed and a variable part proportional to the acceleration to simulate the inertia.

In order to provide more realistic conditions, a fan has been placed in front of the bicycle simulating the wind. The air flow speed was controlled during the simulation as a function of the wheel's speed. The simulated environment consisted of a straight road. Five projectors were fixed in front and beside the cyclist to provide a visual cue with 225° of horizontal and 55° of vertical field of view. A rear screen was placed behind the bicycle to allow a rear-view if the cyclist needs to turn around. The audio cue is simulated by software with the use of an audio system consisting of four speakers and a subwoofer reproducing the sound of the rolling tires (using speed), wind (using speed) and traffic. The simulator is equipped with gear, clutch and braking pedals. Fig. 2 shows the different features of the bicycle simulator.

B. Participants

Ten subjects (6 male; mean age=28.17, SD=3.76 and 4 females; mean age=25.25, SD=2.06) participated in this experiment. All had normal or corrected-to-normal vision. The mean cycling experience of the participants was 12.9 years. The average number of cycling kilometers per month was 62.

Figure 2. A subject during the experiments.

C. Scenario

The experiment took place in a simulated urban environment. The road consisted of two straight sections: the first was a bicycle-bus shared lane, the latter a separate bicycle lane. Traffic was generated in the same and opposite direction of the cyclist and buses were passing the cyclist from time to time. The participants were asked to take a pre-ride in order to familiarize themselves with the simulator. They were asked to maneuver with the simulator and use the different features, such as: handlebar, pedals, gear and brakes. Following the pre-ride, the participants were asked to go for a ride on the bicycle simulator along the virtual street.

The duration of the experiment was around 10 minutes, which we considered long enough to test all the features of the simulator, collect enough date for post-analysis and not exhausting for the participants. The results of the simulation are used to validate the theoretical and the physical model of the bicycle simulator.

At the end of the experiment, the participants filled three questionnaires. The first questionnaire consisted of general information and cycling experience of the participants in real life and using the simulator, followed by the Simulator Sickness Questionnaire (SSQ) [12]; the participants evaluated their experience, through 16 questions, indicating on a scale of four steps (None, Slight, Moderate and Severe) the occurrence of different symptoms during the experiment. The third questionnaire, NASA Task Load Index (TLX) [13], was aimed at evaluating the overall workload of the cycling task, and the importance of each of the 6 work-load-factors under investigation. The questionnaires were available both in English and French as some participants speak only French.

D. Simulation outputs

Fig. 3 shows the speed profile of the bicycle simulator for one of the subjects measured through the incremental encoder attached to the rear wheel of the simulator. We could notice the acceleration and breaking phases at the beginning and end of the experiment.

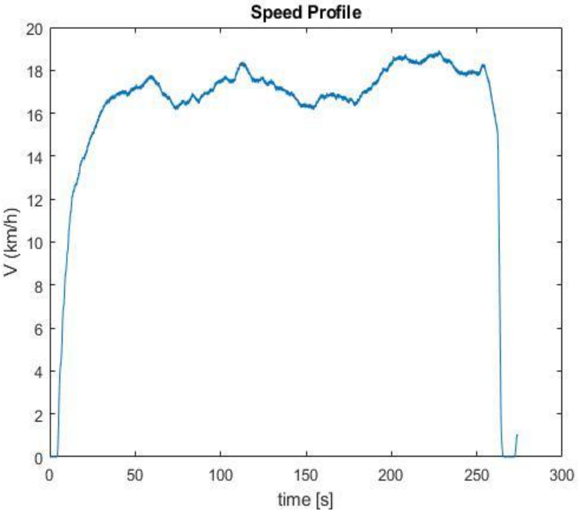


Figure 3. Speed profile of one of the participants in km/h.

The steering angle of the bicycle simulator handlebar, shown in Fig. 4, is measured using an incremental encoder. It is noticed that the steering angle ranges between +\- 4, which is relatively small. This could be explained due to the straightness of the virtual road as noticed in the trajectories and global position (Fig. 5 and 6).

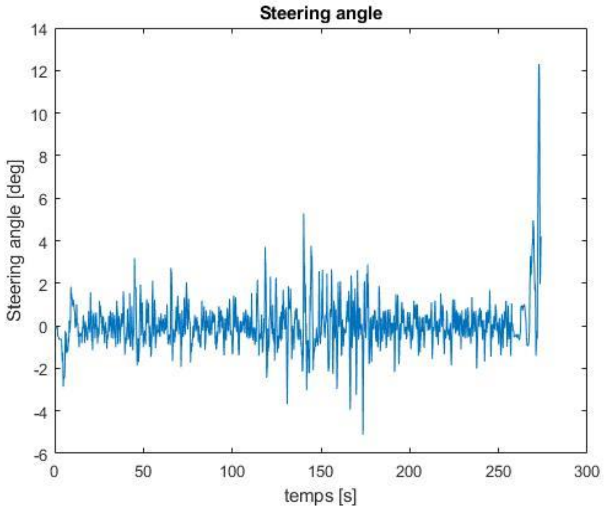


Figure 4. Steering angle of the simulator handlebar.

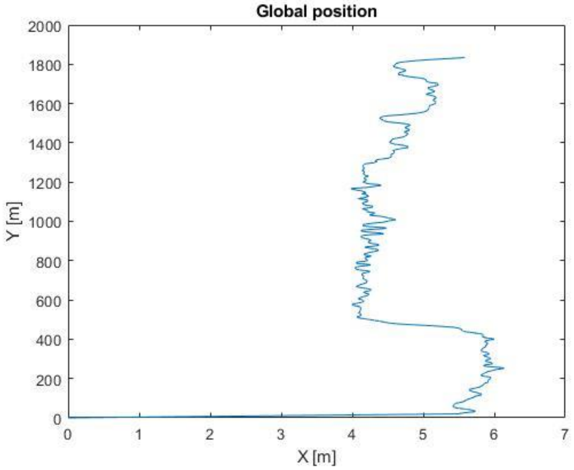
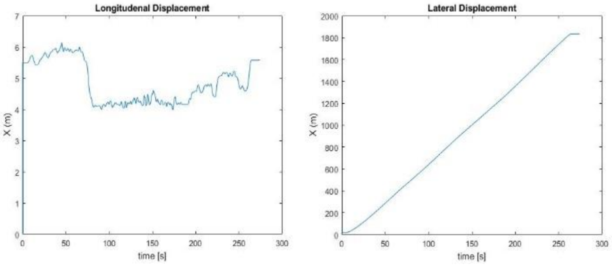


Figure 5. Global position of the simulator extracted from the virtual environment.



(a) (b)

Figure 6. (a) The longitudinal and (b) the lateral trajectory of the simulator extracted from in reference to the virtual environment coordinates.

The estimated friction force calculated using Eq. (1) is shown in Fig. 7.

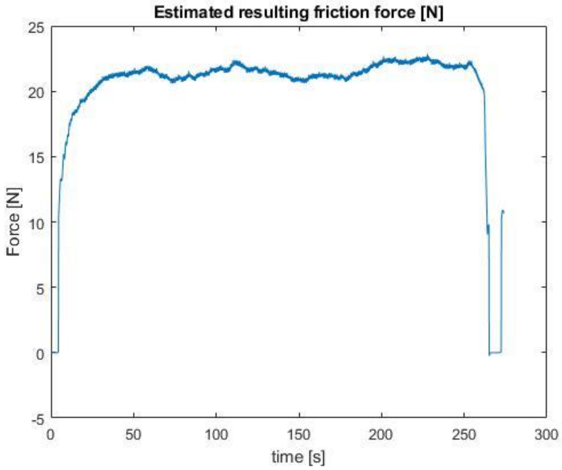


Figure 7. Estimated friction force (N).

IV. SUBJECTIVE VALIDITY RESULTS

A. *Cycling Experience Questionaire*

The results of the first questionnaire are summarized in Appendix 1. As noticed in the last column, the average evaluation of the similarity to cycling in real environment ranges between 4 and 8 on scale of 10 (mean= 6.1, SD= 1,6). Assessing the realism of the simulator, participants mentioned the good design of the virtual road, pedaling, traffic and other sensory ques, such as the wind and the sound of the passing traffic. As suggestions for improvement, most participants agreed they expect higher speed compared to the cycling effort.

B. *Simulator Sickness Questionaire (SSQ)*

The analysis of the simulator sickness questionnaire listed in Table 1 shows that the average total severity of all participants is around 32.5. By comparing this number to the possible scores listed in Table 2, we could see that the total severity of the simulator is slight (less than 78.5). It is also noticed that participants wearing lenses experienced the highest total severity (participant #6 has 115.9 and participant #10 has 71). The affected participants showed high disorientation symptoms.

TABLE I. ANALYSIS OF THE SIMULATOR SICKNESS QUESTIONNAIRE (SSQ).

Participant number	**Total severity**	**Oculomotor**	**Nausea**	**Disorientation**
1	7.48	0	7.58	13.92
2	33.66	9.54	37.9	41.76
3	7.48	9.54	7.58	0
4	0	0	0	0
5	14.96	9.54	22.74	0
6	115.94	114.48	37.9	194.88
7	63.58	38.16	53.06	83.52
8	11.22	9.54	7.58	13.92
9	0	0	0	0
10	71.06	38.16	68.22	83.52
mean	**32.538**	**22.896**	**24.256**	**43.152**
SD	36.80	35.18	23.92	62.75
Min	0	0	0	0
Max	115.94	114.48	68.22	194.88

TABLE II. POSSIBLE SCORE RESULTS OF SSQ.

	Nausea	**Oculomotor**	**Disorientation**	**Total Severity**
none	0	0	0	0
slight	66.8	53.1	97.4	78.5
moderate	133.6	106.1	194.9	157.1
severe	200.3	159.2	292.3	235.6

The average exposition to different symptoms during and after riding the bicycle simulator are reported in the radar chart view (see Fig. 8)

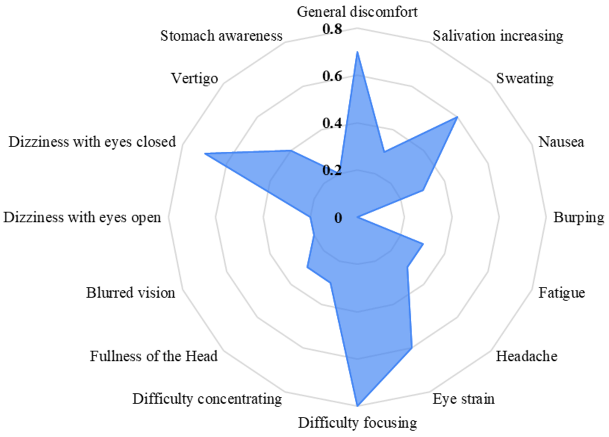


Figure 8. Mean scores observed in each item of the exposure of simulator sickness questionnaire.

C. *NASA Task Load Index (TLX)*

The Nasa Task Load index is used to collect subjective workload assessments for different simulators [13]. Table 3 shows the weighted ratings of the NASA TLX. The first column shows the scales under assessment, the second represents the average weight of each scale according to the personal opinion of the participant. The scorer chooses different factors on an evaluation cards according to its importance, while the weight of each factor is the number of times it was circled. The third column is the average raw rating taken from the TLX questionnaire, where the participants evaluated each factor on a scale of 100. The last column represents the adjusted weighting, which is the multiplication of the weight and raw rating of each factor. It is noticed that the physical demand was highly weighted affecting the overall work load (87.4 on a scale of 100), while the raw rating shows a moderate overall workload.

TABLE III. WEIGHTED RATING OF TLX.

Scale title	**Weight**	**Raw Rating**	**Adjusted rating**
Mental Demand	3	27.78	83.33
Physical Demand	4	47.78	191.11
Temporal Demand	2	31.11	62.22
Performance	1	42.22	42.22
Effort	3	34.44	103.33
Frustration	2	21.11	42.22
Overall workload		**34.07**	**87.41**

Fig. 9 shows the weighted average of each work load factor; the width of each column represents the weight of each factor. We notice the performance was weighted the least, this could be explained because the required task was simple and easy to accomplish, so the participant chose not to give it a high raring.

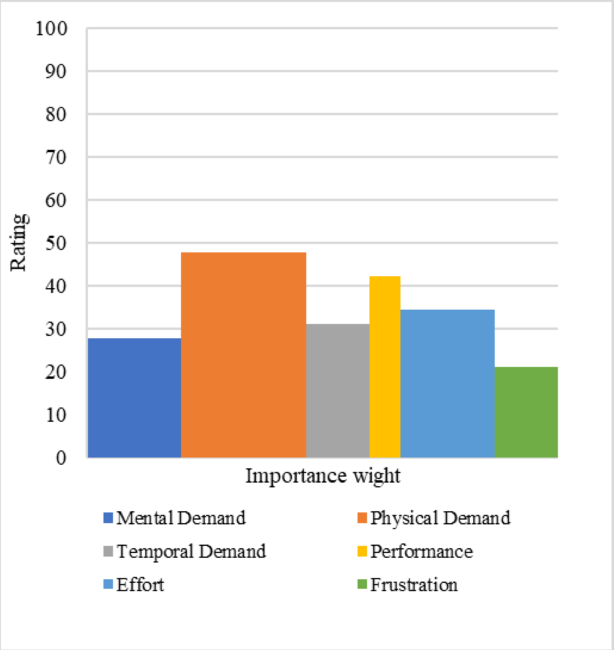


Figure 9. Graphic representation of the composition of a weighted workload score.

V. CONCLUSION AND FUTURE WORK

The bicycle simulator enables us to put cyclists in a riding situation and accurately measure their effective behavior, while controlling the variables at play and avoiding the risks associated with a real environment.

After analyzing the different questionnaires, it is possible to verify the reliability and to subjectively validate the simulator. The results show low simulator sickness and relatively high workload, which could be explained by the effort done by the cyclist.

Further development was applied to the simulator including mathematical model improvements, development of the virtual environment and installment of new devices to simulate the interaction between the infrastructure and the bicycle. An additional experiment, including 36 subjects, was conducted in order to validate the new model physically and subjectively. The results of the new experiment will be published in an upcoming paper.

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APPENDIX I : PARTICIPANTS RESPONSES TO CYCLING EXPERIENCE QUESTIONNAIRE.

Participant Number	**Gender**	**Vision**	**Age**	**Avg. cycling per month (km)**	**Cycling experience (years)**	**Realism of simulator* (Scale of 10)**
1	M	Normal	26	20	20	4
2	F	Glasses	27	3	3	4
3	M	Normal	27	21	21	8
4	M	Normal	30	6	6	6
5	M	Normal	35	7	7	7
6	F	Lenses	23	10	10	6
7	F	Normal	27	20	20	7
8	M	Normal	26	16	16	8
9	M	Normal	25	10	10	7
10	F	Lenses	24	16	16	4