Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 147 (2016) 568 – 572

Procedia Engineering

www.elsevier.com/locate/procedia

11th conference of the International Sports Engineering Association, ISEA 2016

Test Protocol for In-Situ Bicycle Wheel Dynamic Comfort Comparison

Julien Lépine[a]*, Yvan Champoux[b] and Jean-Marc Drouet[c]

[a]*Victoria University, Melbourne, VIC, 8001, Australia*
[b]*Université de Sherbrooke, Sherbrooke, Québec, J1K 2R1, Canada*
[c]*VÉLUS Laboratory, Université de Sherbrooke, Sherbrooke, Québec, J1K 2R1, Canada*

Abstract

Bicycle comfort is very important especially for enthusiastic road cyclists who can spend several hours astride their bicycle in a single ride. Being an abstract concept, several researchers proposed to assess bicycle comfort by measuring the level of vibration transmitted to the cyclist. This can be measured in a controlled laboratory environment but it requires cumbersome and expensive road excitation simulation setup. *In-situ* measurements are an alternative solution but the experiment repeatability is not as good as in the laboratory because many experimental factors are difficult to control while riding a bicycle on the road (e.g. cyclist's posture on the bicycle). This paper presents a test protocol to evaluate bicycle comfort with minimal uncertainty inherent of the *in-situ* experiment. Three main elements are used to enhance measurement repeatability and therefore increase the differentiating capability of the protocol: the measurand selection, the bicycle propulsion and the design of experiments. The power absorbed by the cyclist is used to quantify the level of vibration transmitted to the cyclist because it is far less sensitive to variation of cyclists' posture than to the other measurands used to assess comfort such as acceleration. The bicycle is propelled from an external source which increases precision of the bicycle speed control during the experiment and eliminates measurement noise coming from the bicycle drivetrain. The experiment is specifically designed in term of test runs' duration and replication to improve its repeatability. The protocol is presented in this paper as a case study of bicycle wheel comfort comparison and can be extended to any components or a complete bicycle comfort comparison. The same case study has been performed with different test methods in the laboratory which are used to assess and validate the accuracy of the presented *in-situ* protocol.

Peer-review under responsibility of the organizing committee of ISEA 2016
Keywords: Bicycle Dynamic Comfort; Bicycle Testing; Vibration Measurement; Comfort Measurement;

1. Introduction

In recent decades, significant developments have been made on the weight, stiffness and aerodynamics of road bicycles to improve their performance. In order to further improve road bicycles another characteristic has become increasingly important for cyclists: comfort. Once properly fitted to the cyclist, a more comfortable bicycle is one that transmits less road-induced vibration to the cyclist.

To improve bicycle comfort, it is imperative to adequately measure physical quantities closely related to the perceived vibration transmitted to the cyclist. Indoor (in-laboratory) and outdoor (*in-situ*) measurements are commonly used for this purpose. In-laboratory measurements can be undertaken using a cyclist riding a bicycle on a treadmill [1-3] or using actuators to control the vertical displacement under the wheels. Actuators can excite the bicycle (with a dummy cyclist [4, 5]) using swept-sinusoidal displacement, or to provide a more realistic road excitation, they can replicate actual road profiles [6, 7].

Evaluating the comfort of a road bicycle in the laboratory has many advantages (e.g. better measurement repeatability), but the setup required to replicate the road excitation is complicated and expensive. In contrast, taking measurements outdoors is less expensive, as the bicycle is excited by simply riding along the road. A portable data acquisition system is also required for these measurements and is easily available nowadays. *In-situ* measurements also have the advantage of ensuring that a realistic

* Corresponding author. Tel.: +61 426 242 300.
E-mail address: julien.lepine@vu.edu.au

Peer-review under responsibility of the organizing committee of ISEA 2016
doi:10.1016/j.proeng.2016.06.241

excitation is applied to the bicycle. Several research studies on rider comfort using *in-situ* measurements have been reported [8-12]. The principal drawback of *in-situ* measurements is the lack of repeatability. Various factors that are difficult to control during measurements on the road and can explain this lack of repeatability. For instance: the variation of the cyclist's position has an effect on the dynamic behavior of the bicycle/cyclist system, while the variation in the bicycle speed also plays an important role on the excitation applied to the bicycle. Therefore, assessing cyclist comfort on the road (*in-situ*) is far from trivial and requires careful consideration.

Comfort is a subjective concept; however it could be evaluated using different measurands of the vibration transmitted to the cyclist. The most common for both in-laboratory and *in-situ* measurements is the acceleration transmitted to the cyclist [3-6, 8-12]. This measurand, for the most part, follows the recommendations outlined under ISO standards 2631[13] and 5349[14] on the evaluation and the measurement of vibration transmitted to humans. The force transmitted to the cyclist is also used by some researchers as a comfort measurand [1,2,6]. A third measurand has also been used to assess comfort: the power absorbed by the cyclist [7, 8-9]. According to Pelland et al. [15], this measurand is less sensitive to variation in the cyclist's position and may be well-suited to *in-situ* measurements.

The aim of this paper is to propose a test protocol that can properly evaluate the comfort of bicycles using *in-situ* measurements. The level of power absorbed by the cyclist is used to quantify comfort and no sensory perception qualification and assessment was performed. The protocol is presented in this paper as a case study of bicycle wheel comfort comparison and can be extended to any components or a complete bicycles comfort comparison. The success of this protocol revolves on the measurand selection, the bicycle speed control technique and the design of experiments which consists of comparing the comfort of the same bicycle equipped with two different sets of wheels in several short randomized measurement runs. The same case study has been performed with different test methods in-laboratory which are used to assess and validate the accuracy of the presented *in-situ* protocol.

2. Methodology

While riding a bicycle, cyclists can change their position in different ways. They can put their hands in different locations on the handlebar and can also change their position to apply more or less downward static force on the handlebar. The effects of the cyclist's posture on the vibration transmitted to his hands and buttocks during in-laboratory testing were described by Lépine et al. [6]. In this in-laboratory study, the cyclist's hands remained at all times on instrumented brake hoods and the level of static force applied on the handlebar was monitored and kept as constant as possible. It is, however, more difficult for the cyclist to maintain a constant static force in *in-situ* measurement conditions. This is because the cyclist has to operate the bicycle, and therefore, cannot precisely control the force applied on the handlebar. At the opposite, the bicycle does not move in the laboratory, so the cyclist does not need to operate the bicycle and can more precisely control the static force using an instantaneous force display feedback. On the road, the cyclist has to operate the bicycle and, for safety, it was decided during the test that the cyclist should not be disturbed by an instantaneous force feedback display as used in the lab. Therefore, the cyclist was instructed, as best as possible, to keep the position of his hands constant without any on-site feedback.

To minimize the effect of position variation during the test runs, the power absorbed by the cyclist (absorbed power) was used to assess bicycle comfort. Compared to the acceleration and force measurement, the absorbed power is less sensitive to variation in the cyclist's posture [15]. The absorbed power is measured at the cyclist's hands and buttocks using instrumented brake hoods (Fig. 1) and seat post (Fig. 2) designed for dynamic measurements [16]. The brake hoods were also used to measure the static forces applied by the cyclist in order to evaluate the leaning force on the hood related to the cyclist's position on the bicycle.

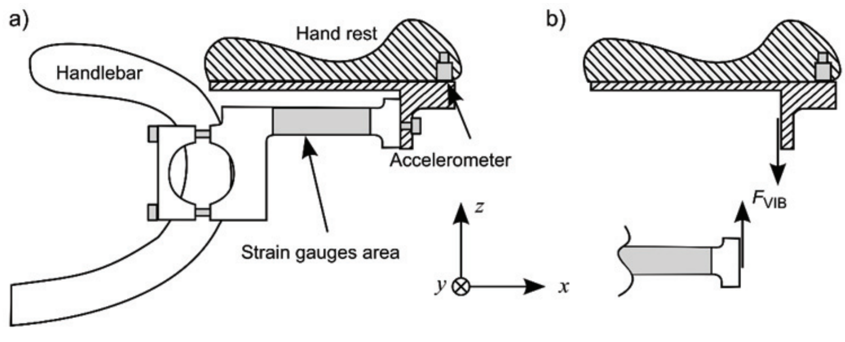

Fig. 1. Instrumented brake hood: (a) transducer position; (b) force measurement point

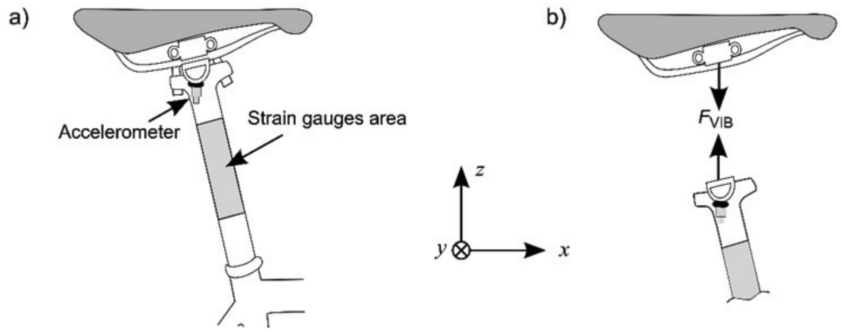

Fig. 2. Instrumented seat post: (a) transducer position; (b) force measurement point

The transducer's signals were recorded using a LMS SCADAS SCR01 data acquisition system, which was carried by the cyclist in a 17 liters backpack. The complete measurement setup weights less than 7 kg which does not significantly alter the cyclist's dynamic behaviour. The sampling frequency was set to 2048 Hz, high enough to cover the measurement spectrum which is concentered below 50 Hz. The system was powered with an internal battery and the data acquisition was controlled using a wireless Bluetooth connection. The bicycle speed was measured with a GPS unit (Garmin Edge 510) and updated every second. Measurements between both devices (SCADAS and GPS) were synchronized by initiating their acquisition simultaneously.

The absorbed power was calculated using the measured vertical force and acceleration signals from the brake hoods and the seat post [17]. All signals were also processed to remove any DC drift. Multiplying the speed v (obtained by integrating the vertical acceleration signal) by the force signal F provides the absorbed power. The average absorbed power over the measurement time T is used as a comfort measurand and is given by (1).

$$P = \frac{1}{T}\int_0^T F(t)v(t)\,dt \qquad (1)$$

The instrumented bicycle components (brake hoods and seat post) were mounted on a high-end carbon fiber road bike (Cervélo R3). The bike was not propelled by the cyclist but instead was pushed by a passenger seated on a small motorbike (49 cc scooter). The derailleurs and chain were removed to prevent additional measurement noise created by those mechanic parts. Three participants are therefore required for the experiments (Fig. 3): (1) the driver, (2) the pusher and (3) the cyclist. The driver is concerned with maintaining a constant bicycle speed using the GPS unit. The pusher sits behind the driver and pushes the cyclist by putting his hand on the cyclist's back. The cyclist attempts to maintain a stable position as best as possible.

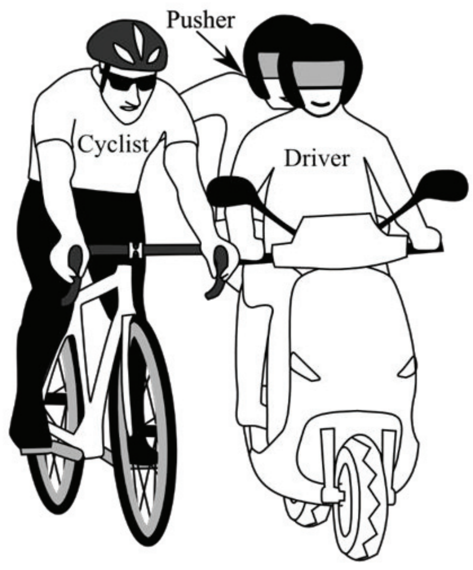

Fig. 3. Bicycle propulsion setup

2.1. Test design

The accuracy of the *in-situ* measurements can be assessed by comparing the influence of the selection of wheels on cyclist comfort. A simple way to perform this task is to compare two different pairs of wheels models as they can be easily and rapidly interchanged. Two pairs of wheels known to have significant difference on the vibration transmitted to the cyclist were selected for the comparison [18]. The wheels transmitting less vibration were the Zipp 202 tubular (Vittoria Corsa CX 21-28 tubular tyre) and more transmitting wheels were the Fulcrum 7 clincher (Vittoria Rubino Pro Slick 700-23c clincher tyre).

In order to limit the effect of the many disturbance factors that occur during *in-situ* measurements (i.e. cyclist position and bicycle speed) the design of experiments of wheels comparison includes test replications to isolate effect of the wheels from the disturbance factors effect. Therefore, each wheel was randomly tested 8 times on the same flat chip-seal road segment without major cracks and aberrations. During the test runs (each lasted 30 s), the cyclist kept a constant "natural" position and the motorbike driver maintained the bicycle speed at 30 km/h.

3. Results

The vibration levels related to the comfort of the two pairs of wheels were compared using the absorbed power at cyclist's hands (left and right separately) and buttocks. ANOVA was performed on both measurands at all three measurement points (SPSW 17.0, IBM). The normality hypothesis was validated. The ANOVA results show significant differences are seen on both brake hoods, with *p*-values of 0.034 and 0.029 respectively on the right and the left brake hoods (Fig. 4). At the seat post, little more differences are observed between both wheels (*p*-value = 0.025). In all cases, the Fulcrum 7 wheels transmitted greater levels of vibration than the Zipp 202. ANOVA performed on the GPS data show no significant difference in the average bicycle speed maintained between test runs of each wheel (*p*-value = 0.96). Therefore the bicycle speed can be considered constant between the test runs and have no effect on the wheel comparison results.

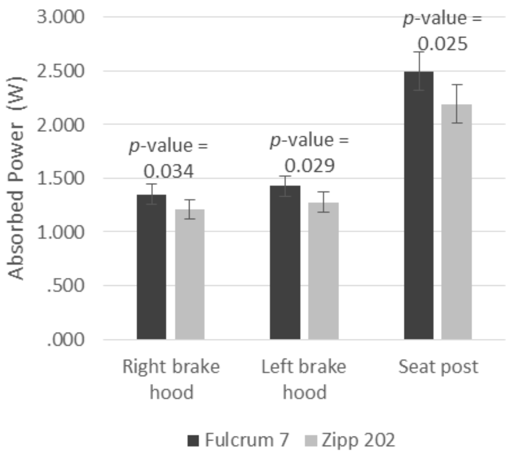

Fig. 4. Wheels comparison results in absorbed power at three measurement points; uncertainty bracket represents 95 % confidence interval

4. Discussion

The assessment of bicycle comfort on the road (*in-situ*) has two main advantages over its in-laboratory counterpart: (1) the relative simplicity of the test setup and (2) the realistic excitation applied to the bicycle. However, drawbacks exist, notably the smaller level of repeatability between measurements.

Measurement repeatability is an expected issue encountered during *in-situ* measurement. It was shown that replicating 8 times each test in a random order on the same road segment gives enough statistical power to compare the comfort between two wheel sets. The absorbed power can distinguish both pairs of wheels on all three measuring points. Previous in-laboratory measurements have also shown significant differences between the same wheels as used in this paper [18]. However the significance level was much lower (*p*-value < 0.000) for only 5 replications per wheel compare to average *p*-value of 0.029 for 8 replications for the measurement made outdoor. This suggests that the lack of control over the cyclist's position increases the measurement variability and makes it more difficult to draw valuable conclusions on bicycle components comfort comparison. This supports the necessity to use several short test runs and to control the bicycle speed with an external propulsion source (e.g. motorbike) when assessing bicycle comfort on the road. Results also confirmed that the absorbed power can overcome the limited control of the cyclist's position during testing. Absorbed power is therefore an appropriate measurand for *in-situ* measurements of bicycle and components vibration transmission and to objectively evaluate comfort.

5. Conclusion

The protocol presented in this paper can successfully differentiate the level of vibration transmitted to cyclist between two pairs of bicycle wheels. Measuring the absorbed power at seat post and brake hoods on a bicycle propelled with a vehicle using short test runs (replicated several times) has proven to be an effective method for *in-situ* measurements to compare and measure vibration parameters related to wheel comfort. This method can be extended to any components or a complete bicycles comfort comparison. However, measurements carried out in the laboratory remain the most precise method to compare the level of vibration transmitted to the cyclist. Any *in-situ* bicycle comfort measurement and assessment should take into account and consider the repeatability issues presented in this paper.

ACKNOWLEDGMENTS

The authors gratefully acknowledge financial support from the National Science and Engineering Council of Canada (NSERC) and the participation of Cervélo and Vroomen-White Design.

References

[1] Richard S, Champoux Y Development of a metric related to the dynamic comfort of a road bike. In: 24th Conference and Exposition on Structural Dynamics 2006, IMAC-XXIV, January 30, 2006 - February 2, St Louis, MI, United states, 2006 2006. Springer New York, p Society for Experimental Mechanics (SEM)
[2] Champoux Y, Richard S, Drouet JM (2007) Bicycle structural dynamics. Sound and Vibration 41 (7):16-+
[3] Hastings AZ, Blair KB, Culligan KF Measuring the effect of transmitted road vibration oncycling performance. In: The Engineering of Sport 5, 2004 2004. International Sports Engineering Assocation, p 619
[4] Thite AN, Gerguri S, Coleman F, Doody M, Fisher N (2013) Development of an experimental methodology to evaluate the influence of a bamboo frame on the bicycle ride comfort. Vehicle System Dynamics 51:1287-1304. doi:10.1080/00423114.2013.797591
[5] Petrone N, Giubilato F Comparative Analysis of Wheels Vibration Transmissibility after Full Bicycle Laboratory Tests. In: AIAS, Palermo, 2011.
[6] Lépine J, Champoux Y, Drouet J-M (2013) Road bike comfort: on the measurement of vibrations induced to cyclist. Sports Engineering 17 (2):113-122. doi:10.1007/s12283-013-0145-8
[7] Lepine J, Champoux Y, Drouet J-M A (2013) Laboratory Excitation Technique to Test Road Bike Vibration Transmission. Experimental Techniques. doi:10.1111/ext12058
[8] Vanwalleghem J, Mortier F, De Baere I, Loccufier M, Van Paepegem W Instrumentation of a racing bicycle for outdoor field testing and evaluation of the cyclist's comfort perception. In: Gomes JFS, Vaz MAP (eds), 2012 2012. INEGI-Instituto de Engenharia Mecanica e gestao industrial, pp 637-638
[9] Vanwalleghem J, Mortier F, De Baere I, Loccufier M, Van Paepegem W (2012) Design of an instrumented bicycle for the evaluation of bicycle dynamics and its relation with the cyclist's comfort. Engineering of Sport Conference 2012 34 (0):485-490. doi:DOI 10.1016/j.proeng.2012.04.083
[10] Hölzel C, Höchtl F, Senner V (2012) Cycling comfort on different road surfaces. Procedia Engineering 34 (0):479-484. doi:10.1016/j.proeng.2012.04.082
[11] Giubilato F, Petrone N (2012) A method for evaluating the vibrational response of racing bicycles wheels under road roughness excitation. Engineering of Sport Conference 2012 34 (0):409-414. doi:DOI 10.1016/j.proeng.2012.04.070
[12] Olieman M, Marin-Perianu R, Marin-Perianu M (2012) Measurement of dynamic comfort in cycling using wireless acceleration sensors. Engineering of Sport Conference 2012 34 (0):568-573. doi:DOI 10.1016/j.proeng.2012.04.097
[13] Iso standard 2631 (1997) Mechanical vibration and shock - Evaluation of humain exposure to whole-body vibration - Part 1: General requirements.
[14] Iso standard 5349 (2001) Mechanical vibration - Measurement and evaluation of human exposure to hand-transmitted vibration - Part 1: General requirements.
[15] Pelland-Leblanc JP, Lepine J, Champoux Y, Drouet JM (2014) Using Power as a Metric to Quantify Vibration Transmitted to the Cyclist. Procedia Engineer 72:392-397. doi:DOI 10.1016/j.proeng.2014.06.067
[16] Drouet JM, Champoux Y (2014) Designing a Strain Gauge Transducer for Dynamic Load Measurement in Cycling using numerical simulation. Procedia Engineer 72:304-309. doi:DOI 10.1016/j.proeng.2014.06.016
[17] Champoux Y, Vanwalleghem J, Drouet J-M Dynamic calibration of an instrumented bike brake hood in measuring power absorbed by the hands. In: ASIA-PACIFIC CONGRESS ON SPORTS TECHNOLOGY, Barcelona, Spain, 23-25 September 2015 2015.
[18] Lépine J, Champoux Y, Drouet J-M (2015) The relative contribution of road bicycle components on vibration induced to the cyclist. Sports Engineering 18 (2):79-91. doi:10.1007/s12283-014-0168-9