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ScienceDirect
Procedia Engineering 112 (2015) 361 – 366
Procedia Engineering
www.elsevier.com/locate/procedia

7th Asia-Pacific Congress on Sports Technology, APCST 2015

Using an alternative forced-choice method to study shock perception at cyclists' hands: the effect of tyre pressure

Simon Richard, Yvan Champoux, Julien Lépine, Jean-Marc Drouet*

VÉLUS Group, Mechanical Engineering Department, Université de Sherbrooke
2500, boulevard de l'Université, Sherbrooke (QC) J1K 2R1, Canada

Abstract

In road cycling, tyre pressure has an influence on both performance and comfort of the cyclist. In this paper, the relationship between tyre pressure and shock perception at the cyclist's hands was quantitatively analysed by measuring the Just Noticeable Difference in Level (JNDL) of tyre pressure. The JNDL was determined by using a three-alternative forced-choice (3-AFC) method. The measurement was carried out on seven healthy subjects exposed to shock-type excitation on a laboratory bicycle treadmill. The dispersion of the measured tyre pressure JNDL (69 to 241 kPa; mean 155 kPa; SD 73 kPa) shows a large variability in the hands' perception of shock in the cyclists tested. This suggests that some cyclists have a better capacity than others to differentiate impact sensory inputs at the hands, making them more likely to discern subtle differences in bicycle response dynamics.

Peer-review under responsibility of the the School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University

Keywords: road bicycle; comfort; tyre pressure; perception; JNDL.

1. Introduction

In cycling, tyre pressure has an influence on both performance and comfort. In road cycling, a bicycle with high tyre pressure is more efficient because it has a lower rolling resistance. However, it is less comfortable because it increases the vibration transfer from the road surface to the cyclist. For long-distance cyclists who may spend

* Corresponding author. Tel.: +1-819-821-8000 ext. 61345; fax: +1-819-821-7163.
E-mail address: Jean-Marc.Drouet@USherbrooke.ca

Peer-review under responsibility of the the School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University
doi:10.1016/j.proeng.2015.07.263

several hours on their bicycle during a single ride, comfort is an important issue, as evidenced in recent literature [1,2] and frequently mentioned in popular cycling magazines.

Previous work [3-6] has mainly focused on the effect of tyre pressure on performance, but to the author's knowledge, there are no publications yet on the perception at the cyclist's hands with respect to tyre pressure. The objective of the work described in this paper is to quantitatively analyse the relationship between tyre pressure and shock perception at the cyclist's hands. More specifically, the key element of this work is the measurement of the minimum change in tyre pressure that cyclists are able to detect in shock conditions. This measurement is called the 'just noticeable difference in level' (JNDL) or the 'difference threshold' of tyre pressure. Increasing our knowledge of the shock perception at the level of the cyclist's hands will lead to a better comprehension of the hands' comfort and help to reduce the risk of injuries related to the hand-bicycle interface, such as the 'handlebar palsy' [13]. Vibration transmitted to the cyclist is a major concern for bike manufacturers and cyclists. A better knowledge of shock perception at the cyclist's hands may be useful to guide bicycle manufacturers in the product design phase.

To determine the JNDL of tyre pressure, a three-alternative forced-choice (3-AFC) method was used, as described by Levitt [7]. AFC methods have also been used for other studies to determine the perception threshold of whole-body vibrations and to measure the JNDL and frequency [8,9]; to determine the JNDL in psychoacoustic measurements [10]; to measure the thresholds for direct sound and early reflections simulated by a virtual reality system [11]; and to measure the hearing threshold and loudness perception [12]. The utility of this method in perception studies and the direct applicability to bike testing favour the use of the 3-AFC method to determine the tyre pressure JNDL.

The bicycle's structural response to road excitation is composed of random and shock-type vibrations. Measurements in the field of human hand-arm vibration response for risk assessment show that shock-type exposure leads to higher energy absorption in the hand and arm compared to non-impulsive exposure when using a specially designed laboratory handle [14]. Based on this result and on the fact that shock-type excitation is a common event on many public roads, it was decided that this study of cyclist hand perception would use shock-type excitation.

2. Methods

2.1. Study subjects and bicycle

Seven experienced male cyclists were recruited from the staff and students at the University of Sherbrooke and a local cycling club (ages 23-57 years old, mean age 39; height 175-183 cm, mean 180; mass 66-84 kg, mean 74). All cyclists were free of injury and did not have a history of relevant illness. Each subject gave written informed consent in compliance with the University of Sherbrooke's ethics committee requirements.

To follow the 3-AFC method described below, all subjects were asked to ride the same carbon fiber road bicycle (Argon18, Helium model, large size) with a set of lightweight Mavic wheels (model Ksyrium, 700C, 18 spokes) equipped with a Michelin Pro Race tyre (23 mm wide). The bicycle was properly adjusted for each subject to achieve a comfortable body position for the test.

2.2. Study protocol

Tests described in this paper were carried out using a bicycle treadmill specifically designed and developed at the University of Sherbrooke for bicycle testing. The treadmill platform is 76 cm wide by 196 cm long and allows ample freedom of movement for cycling. Bicycle shock-type excitation was provided by a circular wooden dowel of 9.5 mm in diameter, glued to the surface of the treadmill belt (Fig. 1a). This allowed application of a repetitive and controlled impact. The rear wheel rested on a support that was slightly upraised from the treadmill surface. Only the front wheel touched the treadmill belt and excitation was therefore applied only to the front part of the bicycle to help the subject focus his attention on shock perception by his hands. The treadmill speed was adjusted to 18 km/h, creating approximately one impact per second.

Cyclists were instructed to adopt a natural and constant position on the bike (seated, with their hands on the brake hoods with no grip force) to avoid perception variability due to positioning. An instrumented stem with strain gages (Fig. 1b) [1] has been used to measure the vertical force applied by the cyclist on the handlebar. In this experiment, an oscilloscope showed the DC component of the instrumented stem force signal in real time. This force corresponds to the portion of the cyclist's weight supported by the hands or leaning force. Subjects were asked to find their natural and comfortable position on the bicycle, corresponding to a certain static level of the force, and to maintain this leaning force throughout the JNDL measurement by looking at the displayed force signal. Experience showed that after a short learning period this was an easy task for the subjects. The test was restarted if the subject failed to maintain a constant body position.

Tyre pressure JNDL was determined using the adaptive alternative forced choice (AFC) method. More precisely, a three interval (3-AFC) paradigm was used with the one-up two-down procedure as described by Levitt [7]. This procedure allows an estimation of the point on the psychometric function for which the individual is able to detect a variation of the stimulus in 70.7 % of the cases [15].

To perform the 3-AFC method, subjects were exposed to a number of trials, each one consisting of two 'reference' stimuli and one 'test' stimulus in random succession. Each stimulus was provided by a 15 s ride on the treadmill using different front tyre pressures: 689 kPa (100 psi) for the reference stimuli (constant throughout the test) and a lower tyre pressure for the test stimulus. The difference between the so-called 'reference' pressure and the 'test' pressure, Δp, was set to 207 kPa (30 psi) for the first trial. After one trial, subjects were asked to answer the following question: which one of the three stimuli was different from the others? Depending on the subject's answer, test pressure was changed according to the one-up two-down procedure: test pressure was increased (Δp decreased) for two consecutive correct responses and test pressure was decreased (Δp increased) for one incorrect response. The initial step-size of 69 kPa (10 psi) was halved after each upper reversal until a terminal step-size of 17 kPa (2.5 psi) was obtained. In this experiment, the test was stopped after the first reversal with the terminal step size. The JNDL result has been taken as the final value of the procedure. Figure 2 illustrates a typical one-up two-down JNDL assessment procedure (black and white squares correspond to correct and incorrect responses respectively).

To facilitate perception comparison, tyre pressures were changed quickly (15 s) between each ride by using two identical front wheels: one with the reference pressure and the other with the test pressure. All trials with a single subject were conducted on the same day, requiring approximately 45 to 60 min of testing per subject. To eliminate audible perception, subjects were asked to wear a headset playing white noise that was loud enough to mask the noise of impact.

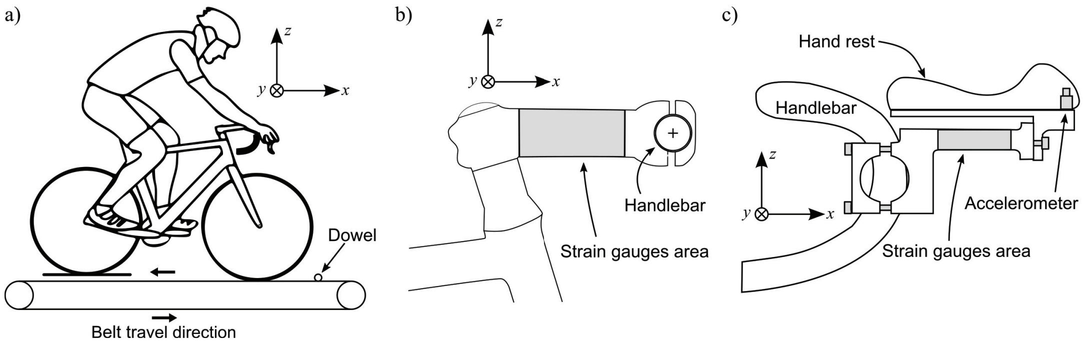

Fig. 1. (a) bicycle treadmill with a wooden dowel attached to the belt; (b) instrumented stem [1]; (c) instrumented brake hood [1].

2.3. Energy absorbed at the cyclist's hands

Several metrics to quantify bicycle comfort for random-type excitation, including acceleration, force and absorbed power, have already been proposed in the literature [16]. For shock-type excitation, the energy absorbed by the cyclist could be an effective metric, since this measurement integrates the magnitude and duration of each impact independently of measurement duration. As an exploratory effort to quantify comfort when shock-type excitation occurs, the authors believe it is relevant to establish a link between the JNDL and the energy absorbed at the cyclist's hands.

In a separate study, the energy absorbed at the cyclist's hands was measured as a function of the front tyre pressure (range: 414 to 689 kPa) using instrumented brake hoods (Fig. 1c) and the identical laboratory set-up. These measurements were performed on an experienced male cyclist (age 46 years old; height 180 cm; mass 78 kg). The instrumented brake hoods have been presented by Lépine [1].

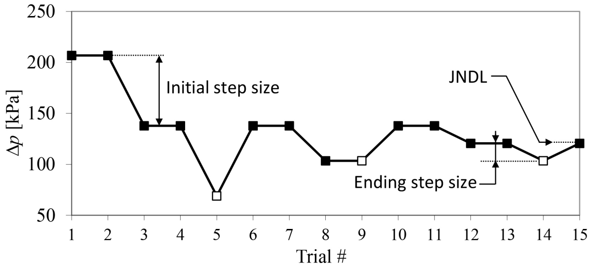

Fig. 2. Typical one-up two-down JNDL assessment procedure.

3. Results

The energy absorbed at the cyclist's hands, E, shows good linearity to front tyre pressure, p, (R^2=0.993) for the pressure range considered (Fig. 3). The slope of the trend line is 4.0 10^{-3} J/kPa.

Figures 4a to 4g show the JNDL assessment for the seven subjects. The JNDL of tyre pressure ranged from 69 to 241 kPa (mean 155 kPa; SD 73 kPa). The number of trials required for the determination of the JNDL varied from 12 to 23, which means that 36 to 69 rides on the treadmill were required depending on the subject. As can be seen in Fig. 4c, 4d and 4g, subjects 3, 4 and 7 did not detect the initial tyre pressure difference of 207 kPa. A greater difference was necessary to start the JNDL measurement procedure. Figure 4a shows that subject 1 adapted to the treadmill testing by missing trial 3 with a tyre pressure difference of 138 kPa, but thereafter succeeded all trials with tyre pressure differences as low as 103 kPa. Subject 3 exhibits the same phenomenon.

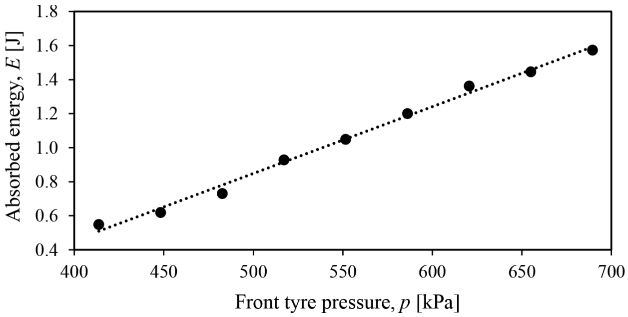

Fig. 3. Energy absorbed at the cyclist's hands vs. front tyre pressure.

4. Discussion

The dispersion of the tyre pressure JNDL (69 to 241 kPa; mean 155 kPa; SD 73 kPa) shows a large variability in the hands' perception of shock in the cyclists tested. This suggests that some cyclists have a better capacity than others to differentiate impact sensory inputs at the hands, making them more likely to discern subtle differences in bicycle response dynamics. A larger test campaign would be necessary to more accurately estimate which physiological factors and interaction of factors can influence the individual JNDL value, but this is beyond the scope of the present study. To the author's knowledge, no other study relative to the present work on hand perception in cycling can be found in the literature to compare outcomes.

a) Subject 1
JDNL = 103 kPa

b) Subject 2
JDNL = 86 kPa

c) Subject 3
JDNL = 224 kPa

d) Subject 4
JDNL = 241 kPa

e) Subject 5
JDNL = 138 kPa

f) Subject 6
JDNL = 69 kPa

g) Subject 7
JDNL = 224 kPa

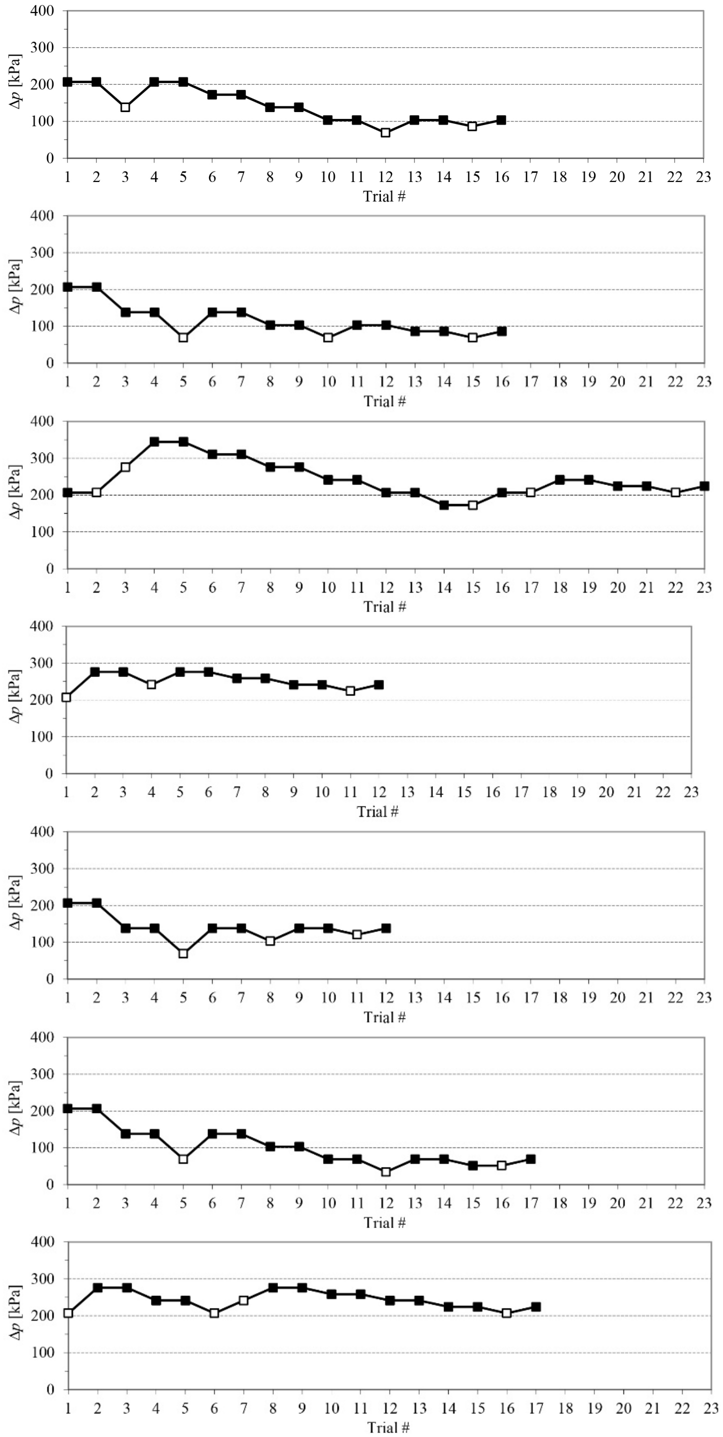

Fig. 4. Front tyre pressure JNDL assessment for the seven subjects.

Using the slope of the trend line shown in Fig.3, the minimum and maximum values of the tyre pressure JNDL (69 kPa and 241 kPa) correspond to a difference in the level of energy absorbed by the cyclist of 0.28 J and 0.96 J respectively. Since the data in Fig. 3 was obtained on a different cyclist than the seven subjects involved in the JNDL study, the aforementioned energy values should be considered as estimates. To obtain accurate energy values for the seven subjects, the relation between the energy absorbed at the cyclist's hands and the front tyre pressure should be established for each subject.

The AFC method has been deemed appropriate and useful for bicycle perception testing. The adaptive character of the method and its convergent behaviour allowed successful measurement of tyre pressure JNDL within a reasonable time period for each subject. Convergence with the final JNDL value has necessitated different numbers of trials depending on the subject and can be influenced by many factors such as the subject's ability and comfort on the treadmill, the subject's fatigue and the JNDL as compared to the initial tyre pressure difference. For measurements with many trials, the cumulative fatigue effect would have to be investigated to ensure reliable JNDL results.

The reference tyre pressure of 689 kPa (100 psi) is commonly used by road cyclists. However, different tyre pressures ranging from 552 kPa (80 psi) to 896 kPa (130 psi) are also used. It may be interesting in a future study to conduct JNDL measurements with another reference tyre pressure, e.g. 896 kPa, to investigate the effect of the reference stimulus on the individual JNDL result.

5. Conclusion

In this paper, we quantitatively analysed the relationship between tyre pressure and shock perception at the cyclist's hands. We successfully measured the tyre pressure JNDL in shock conditions using a 3-AFC method for seven subjects which varies from 69 kPa (0.28 J) to 241 kPa (0.96 J). This method has been deemed appropriate and useful for bicycle perception testing.

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