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## Perceptual Thresholds for Shock-Type Excitation of the Front Wheel of a Road Bicycle at the Cyclist's Hands

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### Abstract

Dynamic comfort when riding a road bicycle is closely linked to road vibration transmitted to the cyclist. The perception of vibration transmitted to the cyclist while riding has recently garnered increased research attention. In this study, we present a laboratory set-up to simulate road cycling on a treadmill and use it to assess cyclist's sensitivity to shock-type excitation. We report a perceptual experiment to estimate the perceptual threshold in terms of the absorbed energy at the cyclist's hands when presented with two closely spaced impacts at the front wheel. Ten cyclists took part in a two-alternative forced choice (2-AFC) discrimination task. The results indicate that they were able to discriminate energy differences in the order of 100 mJ.

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### 1. Introduction

Over the last decade, the dynamic comfort of a road bicycle has become one of the most regarded characteristics by potential buyers and an important design issue for bicycle manufacturers [1]. It is also an increasingly active research field. Dynamic comfort is related to the capacity of a bicycle to filter vibration generated by the road surface, and must be distinguished from static comfort, which is related to the bicycle's size in relation to the size and shape of the cyclist. Many studies have been undertaken in recent years to assess and understand the transmission of road-induced vibration to the cyclist [2-8]. These studies were mainly focused on (1) transducers to measure loads and power transmitted at cyclist's hands and buttocks; (2) test rigs, test protocols and comfort metrics; (3) bicycle and bicycle components vibration transmissibility.

Dynamic comfort is closely linked to the cyclist's perception of road vibration transmitted by his bicycle. Hence bicycle manufacturers try to improve comfort by minimizing the amount of vibration transmitted to the cyclist. However, to determine the effectiveness of vibration reduction, it is critical to assess if cyclists would be able to detect differences in the level of vibration transmitted to their body. From a bicycle engineer standpoint, it is also essential to measure corresponding changes in the amount of vibration transmitted to the cyclist. In the only published study on cyclist's perception, Richard et al. [9] assessed the Just Noticeable Difference in Level (JNDL) of tyre pressure (front wheel only; shock-type excitation) for 7 participants using a three-alternative forced choice (3-AFC) method.

Road cyclists are typically exposed to two types of road excitations: random-type excitation mainly related to road surface roughness and small irregularities, and shock-type excitation caused by potholes and cracks in road surface, or even cobblestones like the ones of the Paris-Roubaix race. Shock-type excitation has a more severe and negative effect on the cyclist body than random-type excitation. Shock-type exposure does not only increase the risk of injuries related to the hand-bicycle interface such

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as the 'handlebar palsy' [10], but it can also be a significant source of discomfort, fatigue and disincentive to ride. For these reasons, we decided to focus on cyclists' perception of shock-type excitation transmitted to the hands.

The present study aims to estimate perceptual thresholds in terms of the absorbed energy at the cyclist's hands for the case of two closely spaced impacts at the front wheel. The perceptual threshold was determined using a two-alternative forced choice (2-AFC) discrimination task. AFC methods are standard sensory discrimination methods commonly used in psychophysics. For instance, they have been used with success to determine the influence of frequency and magnitude on the perception of vertical whole-body vibration [11,12]; or hearing threshold and loudness perception [13].

Several metrics to quantify bicycle comfort for random-type excitation have been proposed in the literature [2-5,7,8,14]: acceleration, force and, more recently, absorbed power. Because it is less affected by the position of the cyclist on the bicycle [14], absorbed power should be preferably used to assess comfort for the case of random-type excitation. For shock-type excitation however, the energy absorbed by the cyclist is a more effective metric, since this measurement integrates the magnitude and duration of each impact independently of measurement duration.

## 2. Methods

### 2.1. Laboratory setup

All the tests described in this paper were carried out using a custom-made bicycle treadmill (Fig. 1a). The treadmill platform is 76 cm wide by 196 cm long and allows ample freedom of movement for cycling. 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 participant focus his attention on shock perceived at the hands. The bicycle and the cyclist were kept vertically stable with bungee cables wrapped around the seat tube and attached to a fixed structure on each side of the treadmill. These bungee cables were selected to be compliant enough in the vertical direction to make sure they did not affect the bicycle's dynamics in that direction, and were able to hold the cyclist and the bike in a vertical position. As required for the paired comparison tests, two circular aluminium dowels differing in diameter were attached to the surface of the treadmill belt to provide two closely spaced impacts. Each attachment system was made up of a pair of sprung clips and allowed for easy and quick change of the dowels. The clips are 15 cm apart and glued to the treadmill belt.

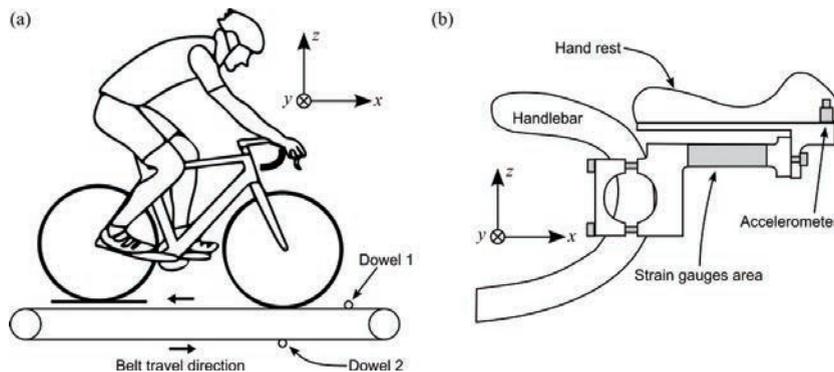


Fig. 1. (a) Bicycle treadmill with two dowels attached to the belt; (b) Instrumented brake hood [2].

The same carbon fiber road bicycle was used for all the tests (Cervélo R3 – size: 56 cm; Fulcrum 7 wheels – size: 700C; Vittoria Rubino Pro tyres – width: 23 mm, pressure: 8 bar). The force and the acceleration transmitted to the cyclist's hands were measured with a strain gauge instrumented brake hood [2] and a PCB 352C68 uniaxial accelerometer under the hands (Fig 1b). The force and acceleration signals were collected using a LMS SCADAS 24-bit acquisition system (model SCR01-08B) at a sampling frequency of 8192 Hz. LMS Test.Lab software was used for data processing. The instantaneous power absorbed at the cyclist's hands,  $P$ , was calculated using (1) where  $F$  and  $v$  (obtained by integrating the acceleration signal) are respectively the instantaneous vertical ( $z$ -axis) force and speed.

$$P(t) = F(t)v(t) \quad (1)$$

The energy absorbed at the cyclist's hands,  $E$ , for each impact was calculated using (2).

$$E = \int P(t)dt \quad (2)$$

## 2.2. Participants and procedure

Ten male cyclists were recruited from the staff and students at the University of Sherbrooke (age 19-45 years old, mean age 25; height 170-185 cm, mean 178; mass 63-77 kg, mean 69). All participants were free of injury and gave written informed consent in compliance with the University of Sherbrooke's ethics committee requirements. They were given practice trials to familiarize themselves with the test environment and feel comfortable on the bicycle so that they could focus their attention on the discrimination task at hand during the test. The bicycle was properly adjusted to achieve an adequate body position for each participant. To eliminate audible perception, participants were asked to wear in-ear headphones playing pink noise and noise blocking earmuffs. To reduce variability in positioning, the participants' posture was controlled as follows:

- They were instructed to find and keep a natural position on the bike with their hands on the instrumented brake hoods with no grip force;
- They did not pedal and remained seated at all times;
- The bicycle cranks were fixed in a horizontal position with the left crank at the front.

Participants were exposed to a series of trials, each consisting of a 'standard' stimulus and a 'test' stimulus. The stimuli were provided by five dowels of different diameters (Table 1) presented pairwise on each trial. The range of dowel diameters was determined in a preliminary pilot test such that the impacts of the pair of dowels std-1 were relatively easy to distinguish and that those of the pair std-4 were difficult to distinguish. The largest dowel ('standard') was always present in a pair and the other dowel ('test') was one of the remaining four, for a total of 4 pairs (std-1 to std-4), each presented in 8 trials, resulting in a total of 32 trials per participant. The order of stimuli presentation (std-test and test-std) within and across trials was randomized to nullify order effect. On each trial, the pair of impacts was repeated three times for a total of 6 impacts per trial. A typical plot of the instantaneous power absorbed at the cyclist's hands for a trial is presented in Fig. 2. The treadmill speed was set to 15 km/h, so that the two impacts in each pair were 0.5 s apart ( $\Delta t_i = 0.5$  s). Two consecutive pair of impacts were separated by a 0.8 s interval ( $\Delta t_p = 0.8$  s), so the stimulus presentation lasted 3.1 s on each trial. After every trial, participants were asked to answer the following question: which of the two impacts has the greater intensity? Their answer was noted by the experimenter before moving on to the next trial. A trial was restarted if the front wheel came in contact with the dowels attachment system. Participants took 45 to 60 min to complete the experiment.

Table 1. Designation and diameter dimension of the dowels.

Dowel designation	Dowel diameter (mm)
1	15.1
2	15.3
3	15.5
4	15.7
standard (or std)	15.9

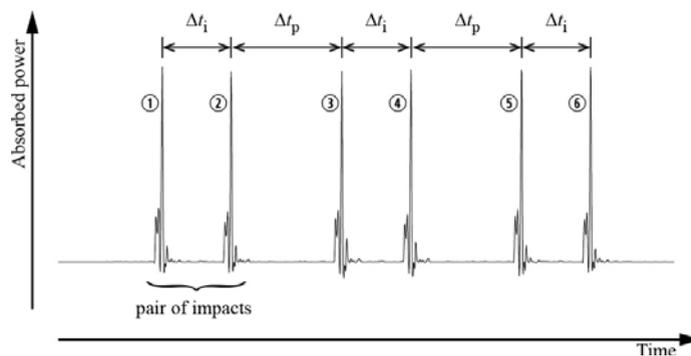


Fig. 2. Typical plot of the instantaneous power absorbed at the cyclist's hands for a trial. The pair of impacts is repeated three times for a total of 6 impacts per trial ( $\Delta t_i = 0.5$  s,  $\Delta t_p = 0.8$  s).

## 2.3. Data analysis

The responses of participants were first analyzed using a repeated-measure ANOVA (analysis of variance) to test the effect of comparison pair on discrimination performance. The proportions of correct responses were collapsed over all participants and presentation orders for each comparison pair.

To quantify the perception threshold, the average absorbed energy difference (left hand-LH and right hand-RH combined) between the first and second impact for the three pairs of a trial,  $\overline{\Delta E}$ , was calculated using (3) where  $E_i$  ( $i=1, \dots, 6$ ) is the energy absorbed at the cyclist's hand during the  $i^{\text{th}}$  impact.

$$\overline{\Delta E} = \left| \frac{1}{6} \left\{ [E_1 - E_2 + E_3 - E_4 + E_5 - E_6]_{\text{LH}} + [E_1 - E_2 + E_3 - E_4 + E_5 - E_6]_{\text{RH}} \right\} \right| \quad (3)$$

We take the absolute value because we are only interested in the energy difference regardless of the order of presentation of the dowels in a trial (standard first or vice versa). The average absorbed energy differences were analysed using an ANOVA.

Finally we estimate the perceptual threshold in terms of absorbed energy difference between pairs of impacts resulting in 75 % correct responses. Indeed, in a 2-AFC discrimination task, the upper limit is 100 % correct responses and the lower limit is 50 % which corresponds to the 'chance level' (random responses). Conventionally, the perception threshold is defined as the stimulus level that yields 75 % correct responses. Perceptual thresholds are usually estimated at the individual level (for each participant) by fitting individual results with a psychometric curve representing the probability of correct responses against stimulus level. Given the small sample size in this exploratory study, we collapsed the discrimination performance results over all participants.

### 3. Results

The total number of correct responses to the question "which of the two impacts has the greater intensity?" for the 10 participants is listed in Table 2. The maximum total number of correct responses for each pair of dowel is 80. The mean and standard errors are displayed in Fig. 3.

Table 2. Number of correct responses for each pair of dowels (maximum of 8 correct responses per pair and per participant).

Participant	Pair of dowels				Total
	std-1	std-2	std-3	std-4	
1	8	8	7	5	28
2	8	7	6	5	26
3	7	6	7	6	26
4	8	6	5	5	24
5	8	7	8	6	29
6	6	7	3	5	21
7	5	5	6	5	21
8	8	8	7	6	29
9	5	5	4	4	18
10	8	6	6	5	25
<b>Total:</b>	71	65	59	52	

The ANOVA revealed a significant effect of comparison pair on the number of correct responses ( $F(3,27) = 9.48$ ;  $p < 0.001$ ). Discrimination performance decreases as the difference in dowel size gets smaller as shown in Fig. 3. Bonferroni post-hoc tests revealed significant differences between std-1 and std-4 (indicated by curly braces in Fig. 3) as well as between std-2 and std-4 ( $p < 0.05$ ). No other significant differences were observed.

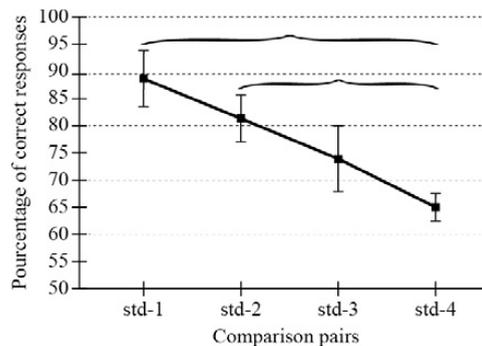


Fig. 3. Discrimination performance (mean and standard error of percentage correct) as a function of comparison pair. Significant differences between pairs are indicated by curly braces.

Mean and standard error values for  $\overline{\Delta E}$  for each pair of dowels are given in Table 3. These values are calculated from the combined results of the 10 participants (80 trials per pair). The ANOVA on  $\overline{\Delta E}$  revealed significant effects of comparison pair ( $F(3,27) = 155; p < 0.0001$ ). Bonferroni post-hoc tests revealed significant differences in  $\overline{\Delta E}$  values among all other comparison pairs ( $p < 0.02$ ).  $\overline{\Delta E}$  decreases as the difference in dowel size decreases.

Table 3. Mean and standard error values for  $\overline{\Delta E}$  for each pair of dowels (in mJ; 80 trials per pair).

		Pair of dowels			
		std-1	std-2	std-3	std-4
$\overline{\Delta E}$	Mean	164	123	102	52
	S.E.	12	12	11	9

To estimate the perceptual threshold, we rely on the stimulus pair yielding 75% correct responses, namely std-3, which corresponds to a difference of 0.4 mm (15.5 to 15.9 mm) of dowel diameter. Expressed in terms of energy absorbed by the cyclist at the hands, this threshold is estimated at 102 mJ, meaning that differences of absorbed energy above 102 mJ were perceptible.

#### 4. Discussion

Results show that the participants were able to discriminate very small differences. This may come as some surprise since the difference in diameter for pair std-3, 0.4 mm or 2.5 %, is barely distinguishable with the naked eye. To our knowledge, such perceptual thresholds have never been quantified before in the context of cycling.

The dispersion of individual total correct responses in Table 2 (ranging from 59 % correct for P9 to 91 % correct for P5) illustrate the inter-individual variability in the group of participants tested. Some cyclists were better than others at differentiating impact sensory inputs at the hands. These findings are in line with the findings of Richard et al. [9] who observed a large variability for front tyre pressure Just Noticeable Difference in Level (min: 280 mJ; max: 960 mJ) with 7 participants. Future research will investigate inter-individual differences as a function of participants' expertise and morphological measurements (such as body mass index).

According to Lépine et al. [2-4], to get repeatable measurements (load, acceleration, power) at the cyclist's contact points with the bicycle and compare the vibrational behaviour of the bicycle/cyclist system, or bicycle transmissibility, it is important to control extraneous variables as much as possible. This also applies to perceptual testing and more specifically absorbed energy measurements. In this study, because the trials lasted only a few seconds, it was not possible to control the static force applied by participants on the instrumented brake hoods using an instantaneous force display feedback. Participants were only instructed to keep their posture on the bicycle as constant as possible within and across trials. They were also instructed not to anticipate upcoming impacts and not to react to them by stiffening their arms. To this end, participants were exposed to preliminary trials to help them become familiar with the experimental setup and the impacts. Experience showed that identifying the first and second impact of a pair was an easy task for the participants.

On methodological grounds, the use of a treadmill for testing was found to be a suitable choice. The loading conditions at the front wheel are similar to those encountered on the road because (1) the wheel rotates and rolls on the dowels and (2) the tyre is deformed locally during the impacts. For these reasons, the treadmill provides a more accurate simulation of road impacts than vertical actuators as those used by Lépine et al. [2-4], and Petrone and Guibilato [8]. However, the treadmill allows less latitude regarding the temporal delays between impacts ( $\Delta t_i$  and  $\Delta t_p$ ). It takes also more time (5 to 10 minutes) for participants to get used to the treadmill mainly because they have to steer the bicycle in a straight line.

This exploratory study will be replicated by independently manipulating several variables to quantify their relative contributions on the perceptual threshold. These variables include the temporal delay between the presentation of the two impacts ( $\Delta t_i$ ), the size of the "standard" dowel, the treadmill belt speed, and the number of repetitions of each impact pair in each trial.

#### 5. Conclusion

In this study, we aimed to determine perceptual thresholds in terms of the absorbed energy at the cyclist's hands for the case of two closely spaced impacts at the front wheel of a road bicycle. Using 10 participants in a 2-AFC discrimination task, this threshold was estimated at 102 mJ. The experimental setup developed for this exploratory study shows great promise for systematic investigation of vibrations transmitted to participants in the context of cycling. The perceptual thresholds derived from these studies could inform the design of more comfortable bicycles. Bicycle manufacturers could utilise the threshold values established a priori through perceptual testing to determine if changes made to a bicycle to improve dynamic comfort will actually be perceptible. One simple means by which this could be achieved in future without actually having to conduct further perceptual tests with participants is by assuming that measured differences in absorbed power can be compared to previously measured thresholds and their associated changes in perception. In cases where these values exceed such thresholds, it could be concluded that such changes are likely to be detected by cyclists.

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