ROAD TO LAB: COBBLESTONE CYCLING VIBRATIONS TRANSFERRED TO THE LAB

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The purpose of the study was to provide vibration recommendations for laboratory-based cycling interventions derived from field tests on cobblestones. For that purpose, the vertical accelerations of the front and rear dropouts (points of wheel fixation at the frame) of the bike frame were recorded, with five experienced cyclists riding on cobblestones at different velocities. Lab vibration recommendations are based on the median frequency (34.6 ± 1.2 – 45.6 ± 0.5 Hz), rms of acceleration (5.5 ± 0.3 - 10.2 ± 0.6 g) , peak acceleration (48.5 ± 3.8 g) , mean amplitude (3.6 ± 4.3 – 5.0 ± 6.4 mm) and peak amplitude (69.7 ± 23.4 mm) of the dropouts. For a lab-based approach with vibration plates, the vibration stimulus should be applied (I) to the rear and front dropout, (II) with two different frequencies used for front (36 - 46 Hz) and rear (32 - 39 Hz) (III) and a mean vertical amplitude of 4 mm. The parameters presented provide the basis for vibration-related material testing, motion analysis or physiological performance testing in cycling.

KEYWORDS: cycling, vibration, acceleration, comfort, laboratory, methods

INTRODUCTION: Vibrations are getting more and more attention in professional cycling and the bike industry. The additional loading due to vibrations is often associated with decreased comfort and injuries (Schwellnus & Derman, 2005; Chiementin, Rigaut, Crequy, Bolaers & Bertucci, 2013) or compromised performance (Filingeri, Jemni, Bianco, Zeinstra, & Jimenez, 2012; Sperlich, Kleinoeder, Quarz, Linville, & Haegele, 2009) in cobblestone races as Paris-Roubaix.

An acute increase in muscular activation, due to classical whole-body vibration is well established (Roelants, Veschueren, Delecluse, Levin & Stinjen, 2006; Pollock, Wolledge, Missl, Martin & Newham, 2010). The increased muscular effort during vibration manifests itself systemically as increased oxygen uptake or increased heart rate (Hazell & Lemon, 2011). Yet these effects are shown for classical whole-body vibration, bicycle-specific results are more heterogeneous. Several groups found effects of vibration on muscular (Munera, Bertucci, Duc, & Chiementin, 2018) or systemic level (Sperlich et al., 2009; Rønnestad, Moen, Gunnerød & Øfsteng, 2018, Viellehner & Potthast, 2019), while others reported contradictory results (Munera, Bertucci, Duc, & Chiementin, 2018; Jemni, Gu, Hu, Marina, Fessi, Moalla, Mkaouer & Konukman, 2019). Different to typical whole-body vibration with one isolated source of vibration, the vibration exposure in cycling is more complex due to multiple contact points to the bike and changing loading within the crank cycle (Munera et al., 2018, Viellehner & Potthast, 2018). Considering an amplitude and frequency-specific muscular sensitivity to vibration (Pollock et al., 2010; Munera et al., 2018), non-uniform test designs with different vibration parameters are a reasonable explanation for contradictory results (Jemni et al., 2019).

To the best of our knowledge, there are no recommendations to simulate bicycle-specific vibrations in a laboratory environment, especially in the context of competitive racing. Therefore, the purpose of the study was to provide based on field tests near reality vibration recommendations for interventions.

METHODS: For the identification of vibration characteristics on cobblestones, five trained and experienced cyclists (71 ± 8.2 kg, 1.83 ± 0.05 m) performed test rides on a cobbled road section. The average size of the cobblestones in the direction of rolling was 98 ± 30 mm, average gap size in between the stones 28 ± 8 mm. A Specialized Tarmac SL5 Expert carbon road bike (Specialized, 2016) was equipped with a mobile bike accelerometry system (DSHS Cologne, ± 50 g, 6 kHz). The frame dropouts (defined as linkade points of the bike frame and wheel axis) are the point of load application to the bike frame, two sensors at the front- and rear dropout recorded vertical accelerations. To create a worst-case loading scenario, no cobblestone specific bike setup was used. Therefore, the bike setup included 25 mm tires inflated with 8 bar. The participants were asked to ride seated on a 200m, flat cobblestone section at a constant speed of 20 km/h, 35 km/h and the individual maximum possible speed ("racing speed" aprox. 45 km/h). This represents the expected speed range of a cyclist on cobbles. Each condition was repeated three times, and data was recorded over 20 seconds for each trial. Acceleration data was sampled at 6 kHz. Based on the findings of Levy & Smith (2005), bandpass filtering (Butterworth, 3-150 Hz, 2nd order, recursive) removed movement artefacts and non-surface induced noise. Vibrations applied to the bike frame are described by the rms of vertical acceleration and the maximum acceleration (mean of 5 highest peaks). Based on the vertical acceleration, the mean and the maximum vertical amplitude (mean of 5 biggest amplitudes) of the drop-outs were calculated. The median frequency summarizes the frequency content of the signal. Due to the small sample size, descriptive statistics were used to define a reasonable range for the laboratory vibration recommendations. All values were determined using Matlab (Matlab R2019B, The MathWorks, USA).

Results: Figure 1 shows an exemplary vertical acceleration signal recorded at the front dropout at 35 km/h in the time and frequency domain. Table 1 summarizes the discrete values. The vibrations at the dropouts are characterized by single vertical acceleration peaks up to 48.5 ± 3.8 g (rear, racing speed) and maximum amplitudes up to 69.7 ± 23.4 mm (rear, racing speed).

Table 1: Time and frequency domain bike vibration characteristics on cobblestones at different velocities for front and rear dropout.

Sensor Position	Speed	Median Frequency [Hz]	Rms Acc [g]	Max Acc [g]	Mean Amp [mm]	Max Amp [mm]
Front dropout	20 km/h	39.3 ± 3.3	6.1 ± 0.5	26.2 ± 2.0	3.9 ± 4.4	34.4 ± 7.7
	35 km/h	43.3 ± 1.5	9.2 ± 0.6	37.3 ± 3.7	3.9 ± 4.2	39.5 ± 10.6
	Racing speed	45.6 ± 0.5	10.1 ± 0.4	45.0 ± 5.2	3.6 ± 4.3	36.6 ± 8.1
Rear dropout	20 km/h	34.6 ± 1.2	5.5 ± 0.3	29.9 ± 3.0	4.1 ± 4.4	35.2 ± 3.6
	35 km/h	35.9 ± 1.4	9.5 ± 0.6	42.3 ± 4.4	5.2 ± 6.0	54.1 ± 9.5
	Racing speed	37.2 ± 1.6	10.2 ± 0.6	48.5 ± 3.8	5.0 ± 6.4	69.7 ± 23.4

Depending on the speed, the rms of vertical acceleration ranges comparable for both dropouts in between 5.5 ± 0.3 (rear, 20 km/h) and 10.2 ± 0.6 (rear, racing speed). The mean amplitudes of both dropouts are for all conditions in a similar range of 3.6 ± 4,3 mm (front, racing speed) to 5.2 ± 6.0 mm (rear, 35 km/h). Figure 1b shows an exemplary single-sided frequency spectrum of acceleration of the front dropout at 35 km/h. The dominant frequency band ranges from 15 Hz to 85 Hz approximately. Depending on the speed, the median frequency ranges at the front dropout from 39.3 ± 3.3 Hz to 45.6 ± 0.5 Hz at and slightly lower at the rear dropout from 34.6 ± 1.2 Hz to 37.2 ± 1.6 Hz.

DISCUSSION: A frequency band in between 15 Hz and 85 Hz approximately demonstrates the complex, stochastic nature of the acceleration signal, with high acceleration peaks close to 50 g, maximum vertical amplitudes up to 70 mm and a speed-dependent rms of vertical acceleration between 6 g and 10 g at the dropouts. While the mean amplitude and rms of acceleration for the front and rear wheel are within a comparable range, a smaller load on the front dropout (De Lorenzo & Hull, 1999) appears to manifest in a higher median frequency at the front dropout compared to the rear.

Technical, ethical and methodological considerations point to a simplified, model-based approach for the initiation of cobblestone vibrations in the laboratory. In addition to the technical challenges of reproducing such a complex signal in the laboratory, the intentional initiation of the high acceleration peaks and amplitudes must be questioned to exclude any risk to the test participants. Also, purely stochastic superimposed vibrations possibly compromise signal processing in EMG-related test designs, since movement artifacts cannot be separated from the biological signal due to the redundant frequency content.

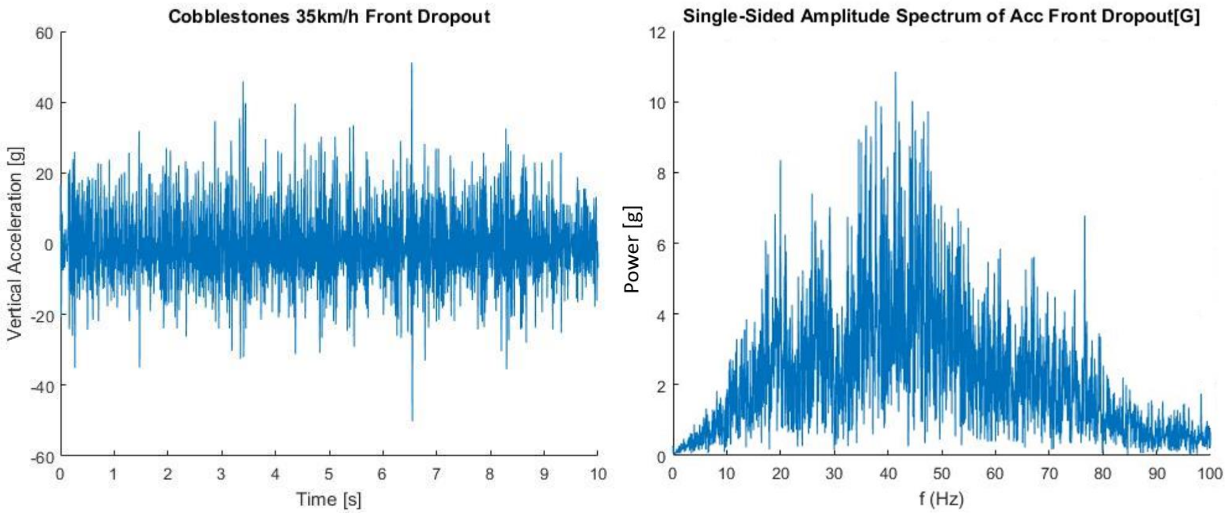

Figure 1: Exemplary illustration of vertical acceleration at the front dropout while riding on cobblestones with 35 km/h. Left: Time-domain signal representation. Right: Single-sided frequency spectrum

Therefore, in a laboratory environment, typically, vibration plates are used for vibration interventions. Although often scalable in amplitude and frequency, this limits the reproduction of the signal to one isolated amplitude and frequency. Based on the outdoor tests, three main recommendations for the application of near reality cobblestone vibration under laboratory conditions can be identified. (I) The vibration stimulus should be applied to the frame via both dropouts (rear and front), as an isolated vibration source probably results in an underrepresentation of the vibration stimulus. (II) The load-related differing frequency content at the front and rear wheel can be reproduced with different frequencies of 36 - 46 Hz for the front and between 33 - 39 Hz for the rear dropout. This recommendation reflects the range of the mean frequencys found at the different speeds. Due to the small sample size a conservative approach, including the standard deviation at the highest and lowest speed-level was choosen for the definition of a reasonable frequency range. (III) A mean vertical amplitude of 4 mm gives an approximation to the front and rear dropout oscillation and is within the capabilities of most vibration plates.

Frequency and amplitude recommendations are within the values reported in the literature for several cycling vibration interventions (Rønnestad et al., 2018; Munera et al., 2018). However, it should be recognized that for realistic loading scenarios, the proposed vibration parameters are based on a direct application into the bike frame. Vibration application into crank only (Sperlich et al., 2009; Jemni et al., 2019; Filingeri et al., 2012), isolated at the rear (Rønnestad et al., 2018) or the front dropouts via the front-tire (Munera et al., 2018) possibly underrepresents a cobblestone vibration stimulus. This should be considered, especially if the findings are interpreted in the context of cobblestone races.

Different surface characteristics or variations in bike setup, as tire width or tire pressure, are expected to influence the vibration parameters. However, based on the relatively small increase of the median frequency over speed and a considerable speed impact on the rms of acceleration, the time domain seems more sensitive to environmental changes. Therefore, factors as tire width, tire pressure, or quality of cobbles are likely to manifest primarily in the time domain, while the frequency content remains comparable. Further research, including different surfaces, tire widths or tire pressures, is needed to confirm the general applicability of the results. Also, due to the preliminary nature of the project, the number of participants is small and therefore, presented data needs to be interpreted with care.

CONCLUSION: Vibration on cobblestones is complex, which makes the transfer into a laboratory environment technically challenging. Laboratory based reproduction of cobblestone-typical vibrations should include simultaneous vibration application into the front and rear dropouts and should take the different mechanical behavior of the front and rear wheel under account. The parameters presented provide the basis for vibration-related material testing, motion analysis and physiological performance testing in cycling. In particular, such a test scenario is applicable in the context of the cobblestones classics for athletes, trainers and the bike industry.

REFERENCES

Chiementin, X., Rigaut, M., Crequy, S., Bolaers, F. & Bertucci, W. (2013). Hand–arm vibration in cycling, *Journal of Vibration and Control,* 19(16), 2551-2560.

De Lorenzo, D. & Hull, M. (1999). Quantification of Structural Loading During Off-Road Cycling, *Journal of Biomechanical Engineering,* 121(4),399-405.

Filingeri, D., Jemni, M., Bianco, A., Zeinstra, E., & Jimenez, A. (2012). The effects of vibration during maximal graded cycling exercise: A pilot study, *Journal of Sports Science and Medicine*, 11, 423-429.

Hazell, T. & Lemon, P. (2012). Synchronous whole-body vibration increases VO2 during and following acute exercise, *European Journal of Applied Physiology,* 112(2), 413-420.

Jemni, M., Gu, Y., Hu, Q., Marina, M., Fessi, M., Moalla, W., Mkaouer, B. & Konukman, F. (2019). Vibration Cycling Did Not Affect Energy Demands Compared to Normal Cycling During Maximal Graded Test, *Frontiers in Physiology,* 10(1), 1083

Levy, M. & Smith, G. (2005). Effectiveness of vibration damping with bicycle suspension systems, *Sports Engineering*, 8(2), 99-106.

Munera, M., Bertucci, W., Duc, S., & Chiementin, X. (2018). Analysis of muscular activity and dynamic response of the lower limb adding vibration to cycling. *Journal of Sports Sciences*, 36(13), 1465–1475.

Pollock, R., Woledge, R., Milss, K., Martin, F. & Newham Di J., (2010). Muscle activity and acceleration during whole body vibration: Effect of frequency and amplitude, *Clinical Biomechanics,* 25(8), 840-846.

Roelants, M., Veschueren, S., Delecluse, C., Levin, O. & Stinjen, V. (2006). Whole-body-vibration-induced increase in leg muscle activity during different squat exercises. *Journal of strength and conditioning research,* 20(1), 124-129.

Rønnestad, B., Moen, M., Gunnerød, S. & Øfsteng, S., (2018). Adding vibration to high-intensity intervals increase time at high oxygen uptake in well-trained cyclists, *Scandinavian Journal of Medicine & Science in* Sports, 28(12), 2473-2480.

Schwellnus, M., & Derman, E. (2005). Common injuries in cycling: Prevention, diagnosis and management. *South African Family Practice*, 47(7), 14–19.

Sperlich, B., Kleinoeder, H., Marées, M. D., Quarz, D., Linville, J., & Haegle, M. (2009). Physiological and perceptual responses of adding vibration to cycling, *Journal of Exercise Physiology online*, 12 (2), 40-46.

Viellehner, J. & Potthast, W. (2018). Acceleration transmitted to the human body during cycling: Effect of a road bike damping system. ISBS - *Conference Proceedings Archive: 36 International Society of Biomechanics in Sports* (2018).

Viellehner, J. & Potthast, W. (2019). Road bike damping: Comfort or performance related? ISBS - *Conference Proceedings Archive: 37 International Society of Biomechanics in Sports* (2019).

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