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MEASUREMENT OF MECHANICAL VIBRATIONS AND MUSCULAR ACTIVITY IN CYCLING ON COBBLESTONES AT RACE PACE – A SINGLE CASE STUDY

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The aim of this research is to reveal the best bike configuration, wheels, and tyre pressure for competitive cycling on cobblestones. One former professional cyclist performed 16.75 laps on a cobbled road track (1.55 km). Three accelerometers were mounted on the stem, the seat post and the down tube. sEMG of the rectus femoris, vastus lateralis, tibialis anterior, extensor digitorum, and thoracolumbar fascia were measured by wireless sensors that measured also soft tissue longitudinal accelerations. The pressure inflated on tubular tyres led to significant differences on effective values of vibrations, each time higher at 5.5 rather than 5 bar. The methods implemented in this study appear to be consistent in revealing the best bike configuration and settings when vibrations are the main elements in races.

KEYWORDS: accelerometers, electromyography, transmissibility, soft tissue movement, bike settings, professional cycling.

INTRODUCTION: Winning a classic cycle race like Paris-Roubaix or the Tour of Flanders remains a dream for numbers of professional cyclists. Those two races present the particularity to include over 20 cobbled sections. From laboratory experiments, Lépine, Champoux, and Drouet (2014) explained how the frame, the fork, and the wheels might change the mechanical vibrations transmitted from the road to the cyclist. The only study in the field focused on mountain biking and differences induced by wheel size (Macdermid, Fink, & Stannard, 2014). To reduce the effective values of vibrations suffered by the cyclists, it seems interesting to choose the most appropriate bike and settings. The aim of this research is to reveal the best bike configuration (from two frame-fork configurations already selected after laboratory tests on a vibration platform), the best wheels (differentiated by their rim height) and the best tubular tyre pressure for competitive cycling on cobblestones with the use of both accelerometry and electromyography (Arpinar-Avsar, Birlik, Sezgin, & Soylu, 2013). Our main hypotheses are that both rim height and tyre pressure present effects on mechanical vibrations in actual conditions.

METHODS: One former professional cyclist (35 years old, 1.8 m height and 78 kg of body mass) performed 16.75 laps on a cobbled road track (1.55 km of length in front of the Chateau de Chantilly, France). He had to keep pedalling and to reproduce his cycling speed on four different parts of the track: one downhill with low cobblestones (DownH_LowC), one uphill with high cobblestones (UpH_HighC), one downhill with high cobblestones (DownH_HighC), then one uphill with low cobblestones (UpH_LowC). During the uphill parts (slope between 3 and 4%), the cyclist was required to ride as fast as in races, to keep his hands on the top of the handlebar, and to use the same gear ratio (53x21) and pedalling cadence. Just this sole specific participant is required by this protocol designed to study the bike behaviour (Lépine, Champoux, & Drouet, 2014).

Two different fork-frame configurations, two pairs of wheels and three tubular tyre pressures were tested according to the experimental plan presented on Table 1.

Three tri-axial accelerometers (HiKoB Fox, HiKoB, Villeurbanne, France) were firmly mounted on the stem, the seat post, and the down tube (near the bottom bracket) of each bike. Only the longitudinal acceleration measured along the seat post and the normal accelerations measured on the stem and on the down tube (sampled at 1350 Hz) were used to assess the effective values of vibrations.

Table 1: Experimental plan

Condition	Bike	Wheels	Tyre pressure	Number of laps
C1	1	35 mm	4.5 bar	1.75 ^a
C2	1	35 mm	5.0 bar	3
C3	1	35 mm	5.5 bar	3
C4	1	50 mm	5.5 bar	3
C5	2	35 mm	5.0 bar	3
C6	2	35 mm	5.5 bar	3

^abefore puncture

Cycling speed and geolocalisation (latitude, longitude, and altitude) were measured continuously with a GPS device mounted on the stem (Garmin Edge 800, Garmin, Kansas City, U.S.A.). Power output and cadence were measured only on bike 1 with a built-in SRM powermeter (SRM, Jülich, Germany) and pedalling data were logged on the GPS device at a sampling rate of 1 Hz.

Surface electromyographic signals (sEMG) of the rectus femoris (RF), vastus lateralis (VL), and tibialis anterior (TA) muscles for the right lower limb, extensor digitorum (ED) for the right forearm, and thoracolumbar fascia (TF) for the back were measured simultaneously by five wireless active sensors (37 x 26 x 15 mm, 15 g) which consist in two dry bar electrodes (10 x 1 mm) spaced by 10 mm (Trigno Lab, Delsys Inc., Natick, U.S.A.). Electrode skin areas were shaved, rubbed with an abrasive paste, and cleaned with alcohol solution. The sensors were attached to the skin with a double-sided adhesive interface tailored to match the contours of the electrodes. They were placed on the middle of the muscle belly and positioned in the direction of the muscle fibres, following the recommendations of De Luca (1997). These sensors also measured soft tissue movements by integrated tri-axial accelerometers (only the longitudinal acceleration was handled). They were secured with adhesive tape and the cyclist wore winter cycling clothes (jersey and tights) to prevent their fall due to undergone vibrations. sEMG and accelerations signals were sampled at 2000 and 148 Hz, respectively, and wirelessly transmitted to a laptop in a following vehicle.

All raw signals were synchronized *a posteriori* by recognition of particular events, then cut for each part of the track and condition (10 s for both downhill parts, 30 s for UpH_HighC, and 15 s for UpH_LowC). For each acceleration (from sensors mounted on bike or placed on cyclist's muscles), the mean value was subtracted to the raw signal freeing it from the orientation of the sensor. Effective values of vibrations were then assessed by calculating the root mean square (RMS) of these variations. Mean values for cycling speed, power output, and pedalling cadence were also computed. sEMG signals were filtered using a band-pass filter (10-500 Hz) then intensity of each muscle was quantified by their RMS values and normalized to the maximal RMS value observed during a sprint exercise performed on a flat road without cobblestones. All data processing was conducted with specific scripts (Matlab R2014a, MathWorks, Natick, U.S.A.).

For each sensor position, the means of effective values of all laps (from one to three according to the condition) from the same part of the track were computed. These means were compared with a paired t-test (StatPlus:mac LE, AnalystSoft Inc.). Paired t-test let to assess bike configuration, wheels, and pressure effects by analysing the sole differentiation between two conditions (e.g. C2 vs C3 for pressure effect). Computing the means prevent the emergence of lap effects that one does not study. As this test assumes that the difference between pairs follows a Gaussian distribution, the normality of this difference was also controlled with Shapiro-Wilk's test. All criteria of significance were chosen at 5%.

RESULTS: Bike configuration, wheels and pressure effects were assessed on effective values of vibrations for uphill or downhill slopes, for low and high cobblestones from sensors mounted on bike (Table 2), and only for UpH_HighC from sensors placed on the cyclist's muscles (Table 3). Pressure effect was detailed on bike 1 which was tested with three different tubular tyre pressures (Figure 1). Bike and pressure effects were also assessed on muscular activations for UpH_HighC (Table 4). Large coefficients of variations found for ED and RF led us to explore the evolution of sEMG within a given condition (from the first to the third lap) and within the whole experiment (from C1 to C6, see Figure 2).

Table 2: Bike, wheels and pressure effects according to the slope or the cobblestones

Effect	Effective value (Mean \pm SD, m.s ⁻²)					
	Uphill	Downhill	LowC	HighC	Total track	
Bike	C2&C3	31.1 \pm 8	42.0 \pm 7.0	34.1 \pm 9.0	39.0 \pm 9.3	36.6 \pm 9.5
	C5&C6	29.9 \pm 8	43.1 \pm 7.1	33.0 \pm 9.7	40.0 \pm 9.4	36.6 \pm 10.2
	p-value	0.156	0.208	0.340	0.027	0.955
Wheels	C3	32.7 \pm 8.4	44.1 \pm 6.6	36.3 \pm 9.7	40.5 \pm 9.3	38.4 \pm 9.4
	C4	32.7 \pm 8.5	42.0 \pm 8.2	33.9 \pm 8.1	40.8 \pm 9.9	37.4 \pm 9.3
	p-value	0.871	0.160	0.087 ^b	0.332	0.150 ^b
Pressure	C2&C5	29.1 \pm 8.0	41.2 \pm 7.2	32.2 \pm 9.5	38.1 \pm 9.2	35.2 \pm 9.9
	C3&C6	31.9 \pm 7.8	43.9 \pm 6.7	34.9 \pm 9.0	40.8 \pm 9.2	37.9 \pm 9.6
	p-value	0.000	0.006	0.005	0.000	0.000

^bThe distribution of the difference between C3 and C4 for LowC or Total track isn't normal. This may be due to large differences for effective values during the DownH_LowC where the cyclist didn't ride at the same speed; higher speeds leading to higher effective values (see Discussion).

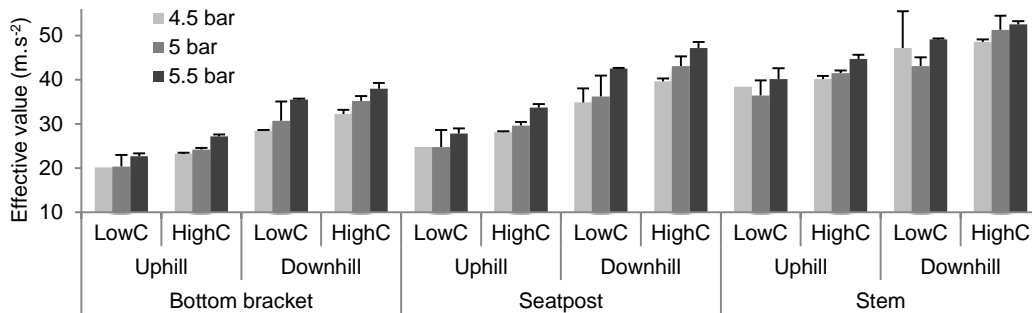


Figure 1: Pressure effect on bike 1 equipped with low profile wheels

Table 3: Wheels and pressure effects on muscles' vibrations^c

Effect		Effective value (Mean \pm SD, m.s ⁻²) on UpH_HighC						All (p-value)
		ED	RF	TA	TF	VL		
Wheels	C3	16.1 \pm 0.1	10.5 \pm 0.3	12.4 \pm 0.1	6.1 \pm 0.1	9.1 \pm 0.2	10.8 \pm 3.7	(0.106)
	C4	16.1 \pm 0.0	10.3 \pm 0.2	11.8 \pm 0.1	6.0 \pm 0.2	8.9 \pm 0.1	10.6 \pm 3.7	
Pressure	C2&C5	31.6 \pm 16.8	11.9 \pm 1.4	15.5 \pm 3.6	6.5 \pm 0.4	10.3 \pm 1.3	15.1 \pm 11.8	(0.237)
	C3&C6	31.6 \pm 17.0	11.9 \pm 1.6	15.6 \pm 3.5	6.7 \pm 0.7	10.3 \pm 1.3	15.2 \pm 11.9	

^cThe bike effect wasn't assessed on effective values of muscles' vibrations because a change in sensors settings was made before C5. Thus C2 and C5 have not been compared, neither did C3 and C6.

Table 4: Bike and pressure effect on muscular activations^d

Effect		sEMG (Mean \pm SD, %max) on UpH_HighC					All (p-value) ^e
		ED	RF	TA	VL		
Bike	C2&C3	6.0 \pm 1.3	6.9 \pm 1.6	27.3 \pm 0.7	20.7 \pm 1.0	15.2 \pm 9.8	(0.761)
	C5&C6	7.8 \pm 1.5	6.6 \pm 0.8	25.6 \pm 3.2	22.2 \pm 1.9	15.5 \pm 9.1	
Pressure	C2&C5	7.2 \pm 1.1	7.5 \pm 1.1	25.4 \pm 2.8	21.1 \pm 0.8	15.3 \pm 8.8	(0.889)
	C3&C6	6.6 \pm 2.0	6.0 \pm 0.8	27.5 \pm 1.4	21.7 \pm 2.3	15.4 \pm 10.1	

^dThe wheels effect wasn't assessed because of the number of observations.

^eThe EMG sensor placed on TF muscle didn't work properly during C5. We didn't include these data on the study.

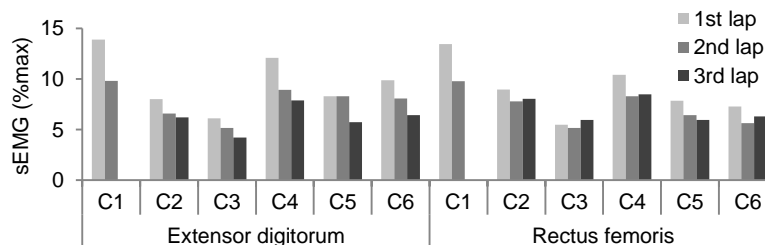


Figure 2: Evolution of sEMG for ED and RF

There wasn't any significant effect for the bike configuration except when riding on high cobblestones where mean effective value is higher on bike 2. Results didn't present either significant effect for the height of the rim whatever the part of the track. The pressure inflated on tubular tyres however led to significant differences on effective values of vibrations (on

bike, no differences on muscles' vibrations), each time higher at 5.5 rather than 5 bar.

DISCUSSION: Results found for the bike effect should lead the cyclist to choose the bike 1 to race on this road. Indeed no differences were found between the two bikes except when riding on high cobblestones where bike 1 presented restrained vibrations. While the two bikes' results appeared similar on laboratory tests, the present study in actual conditions helps the professional team to make decisions.

Results found for the wheels effect presented no significant differences. Here, it is important to explore the non-normality of some data that may be due to the non-respect of the task. Indeed the cyclist had to ride at the same speed for each part of the track as set previously. The higher effective values (n.s.) found for the low profile wheels on downhill (44.1 vs. 42.0 m.s⁻² for high profile wheels) and low cobblestones (36.3 vs. 33.9 m.s⁻²) correspond to higher cycling speed on the downhill and low cobblestones part of the track (DownH_LowC, 34.0 ± 0.9 km.h⁻¹ vs. 31.4 ± 0.4 km.h⁻¹). This relation between effective value and speed is also shown on Figure 1 where effective values on downhills are always higher than on uphills, downhill parts ridden faster (31.4 ± 1.9 km.h⁻¹ vs. 22.0 ± 1.9 km.h⁻¹).

Results found for the pressure effect should lead the cyclist to inflate their tubular tyre below 5.5 bar. Significant differences were found between 5 and 5.5 bar on all parts of the track. Furthermore the extra condition tested on bike 1 (4.5 bar) tends to confirm these results. This test was however interrupted because of a flat tyre on the second lap. It thus appears risky to choose such low pressure to race on this type of road because flat tyre may cause accidents and influence mainly overall performance. On this specific point, more tests must be conducted to establish flat tyre occurrence statistics as well as vibrations results for more tyre pressures. Future studies must establish the relation between tyre pressure and cycling performance (considering fatigue, efficiency, speed, i.e. systemic analysis).

Results found for muscular activations didn't show any effect of bike configurations and settings. The activation of ED however seemed to decrease during each condition as if the cyclist released tension from his muscle. A similar trend was found for RF but with a slight contraction during the last lap. These evolutions might be due to slight changes in posture adopted on the bike. These behaviours must be studied with more observations and a specific designed protocol. In any case muscular activation assessment is achievable in the field in such challenging conditions.

CONCLUSION: The methods implemented in this study appear to be consistent to reveal the best bike configuration and settings for competitive cycling when vibrations are the main elements in races. Vibration assessments on bike and on cyclist seem reliable as long as sensors are configured in a proper way (acquisition scale and frequency). Our two main hypotheses are answered by the present study in actual conditions and the use of proper statistical tests: while the rim height didn't present any effect on mechanical vibrations (between 35 and 50 mm), the tyre pressure did. Specifically this study helped choose the best tubular tyre pressure according to the profile of a race. It appears that low pressures (< 5.5 bar) led to restrain the effective values of vertical vibrations met at cyclist-bike interfaces but flat tyre could also occur. More participants and a new experiment designed to assess the effects of settings on cycling performance should now be proposed.

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