GRAVEL BIKE VIBRATIONS

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The purpose of this pilot study was to explore the vibration exposure of Gravel bikes at different tire pressures. Therefore, 9 cyclists (73.7 ± 10.2 kg, 1.78 ± 0.06 m) rode a 150 m flat gravel section at a constant speed of 25 km/h with three tire pressure conditions (1.5, 2.5, 3.5 bar). Horizontal and vertical accelerations at the front dropout (FDO) and rear dropout (RDO) were recorded. Reducing the tire pressure from 3.5 to 1.5 bar resulted in a significant decrease in the resulting acceleration at the FDO from 3.41 ± 0.18 g to 2.07 ± 0.07 g and at the RDO from 2.78 ± 0.14 g to 1.56 ± 0.07 g. When comparing the ratio of horizontal and vertical rms of acceleration, ratios of up to 0.9 for the FDO and up to 0.47 for the RDO were found. This indicates that horizontal accelerations, especially at the FDO contribute considerably to the overall vibration exposure of the bike. The two main conclusions are that (I) damping systems in gravel bikes should take into account not only vertical but also horizontal accelerations and (II) tire pressure adjustment has a similar potential for vibration management on gravel as more complex damping systems.

KEYWORDS: cycling, vibration, acceleration, gravelbike

INTRODUCTION: Gravel-Biking is a growing trend in cycling and has become an exciting new way to explore the outdoors. Gravelbikes are generally considered to be more versatile than conventional road bikes, as their wider and profiled tires allow them to go both on paved roads and off-road. However, the vibration exposure associated with riding on gravel surfaces has been relatively unexplored. This pilot study aims to explore the vibration exposure of gravel bikes at different tire pressures on gravel roads.

Previous research indicates that vibration affects the riding comfort and performance of athletes, particularly during prolonged periods of cycling (Viellehner & Potthast, 2021; Chiementin, Rigaut, Crequy, Bolaers & Bertucci, 2013). Vibrations mechanically stimulate the musculoskeletal system, resulting in increased muscular activation of muscles, which translates into an overall higher energy demand (Viellehner & Potthast, 2021). Although the modest magnitude of these effects suggests that the influence on performance is small over a short-term period, it seems plausible that due to the interaction of comfort and performance, vibration exposure is of particular importance in longer exposure scenarios such as Gravel-Biking. Therefore, reducing the athlete's vibration exposure has become a main objective for industry and athletes. For athletes, adjusting the tyre pressure is the most basic measure to control the vibration exposure. From an engineering point of view, information on the direction and strength of the accelerations to which the bicycle is exposed can help define the requirements for design parts or damping systems.

Previous work has focused on the accelerations at the wheel axes of road bikes on cobblestones (Chiementin et al., 2013; Viellehner & Potthast, 20019), or the forces acting on mountain bikes when riding off-road (Lorenzo & Hull, 1999). As the vibration exposure is a result of the interaction between the cyclist, the bike, and the terrain it is unclear whether these results can be applied to gravelbikes as well. Furthermore, only limited information is available about the characteristics of the horizontal and vertical accelerations acting on the bicycle. Therefore, the purpose of this pilot study was to provide (I) information about the magnitudes and direction of the vibration input to the bike on gravel and (II) the effects of tire pressure modifications on vibration exposure.

METHODS: To assess vibration exposure on Gravel bikes, 9 cyclists (73.7 ± 10.2 kg, 1.78 ± 0.06 m) rode a 150 m flat gravel section at a constant speed of 25 km/h with three tire pressure conditions (1.5, 2.5, 3.5 bar). The tire pressure was defined to cover the entire spectrum of pressures usually used. The speed was controlled and kept constant (±1 km/h) by the participants with a GPS device (Edge 530, Garmin Ltd., Schaffhausen, CH). The test track was on a typical agricultural dirt road with a mixture of dirt, gravel and minor erosion. A Scott Addict Gravel 10 bike (Scott Sports SA, CH, 2021) was equipped with an accelerometry system (DSHS Cologne, ± 50 g, sampling @6 kHz) consisting of two acceleration sensors, measuring horizontal and vertical accelerations at the front dropout (FDO) and rear dropout (RDO). These are the points where the load is applied to the bicycle frame via the wheels. The bike setup included carbon rims (Capital 1.0 X40, Syncross, CH) and 700x45c tires (G-One Bite performance, Schalbe, GER). Data sampling frequency was 6000 Hz, with a bandpass filter (Butterworth, 3 - 500 Hz, 2nd order, recursive) applied to remove movement artefacts due to pedaling and non-surface-induced noise. Vibration exposure was expressed as rms and the peak acceleration (mean of 10 highest peaks) in the horizontal and vertical direction. To determine if there is a statistically significant effect of tire pressure on the horizontal, vertical, and resultant rms of acceleration at FDO and RDO, one-way repeated measures ANOVAs were run. Normal distribution of the data was assessed by boxplot and Shapiro-Wilk test. Descriptive and inferential statistics were conducted using Matlab (Matlab R2019B, The MathWorks, USA).

RESULTS: The data were normally distributed for each testing condition. A reduction in tire pressure resulted in a significant decrease of the horizontal (FDO: $p < .001$, partial $\eta2 = 0.917$; RDO: $p < .001$, partial $\eta2 = 0.939$), vertical (FDO: $p < .001$, partial $\eta2 = 0.914$; RDO: $p < .001$, partial $\eta2 = 0.907$) and resultant (FDO: $p < .001$, partial $\eta2 = 0.987$; RDO: $p < .001$, partial $\eta2 = 0.913$) rms of acceleration at both dropouts and all tire pressure levels (figure 1). Discrete values and results of the Bonferroni corrected post hoc pairwise comparisons are presented in table 1.

Table 1: Time domain bike vibration characteristics on gravel at different tire pressures for front and rear dropout. 'A': sig. difference between 1.5 and 2.5 bar, 'B': sig. difference between 2.5 and 3.5 bar, 'C': sig. difference between 1.5 and 3.5 bar (p< 0.05)

		RMS of acceleration (g)			Peak acceleration (g)	
Sensor	Tire pressure	vertical	horizontal	resultant	vertical	horizontal
FDO	1.5 bar	1.54 ± 0.05 [B, C]	1.38 ± 0.08 [B, C]	2.07 ± 0.07 [B, C]	7.54 ± 0.93 [B,C]	9.02 ± 1.79 [C]
	2.5 bar	2.12 ± 0.24 [A, C]	1.79 ± 0.17 [A, C]	2.78 ± 0.28 [A, C]	10.18 ± 1.59 [A]	11.79 ± 2.63
	3.5 bar	2.65 ± 0.18 [A, B]	2.15 ± 0.10 [A, B]	3.41 ± 0.18 [A, B]	12.64 ± 1.90 [A]	13.64 ± 1.95 [A]
RDO	1.5 bar	1.41 ± 0.07 [B, C]	0.67 ± 0.03 [B, C]	1.56 ± 0.07 [B, C]	6.67 ± 0.61 [B, C]	3.57 ± 0.47 [C]
	2.5 bar	2.00 ± 0.30 [A, C]	0.89 ± 0.08 [A, C]	2.19 ± 0.31 [A, C]	9.62 ± 1.91 [A, C]	4.70 ± 1.10
	3.5 bar	2.56 ± 0.15 [A, B]	1.08 ± 0.03 [A, B]	2.78 ± 0.14 [A, B]	13.75 ± 2.01 [A, B]	5.75 ± 0.96 [A]

Peak vertical accelerations of up to 12.64 ± 1.90 g and peak horizontal accelerations of up to 13.64 ± 1.95 g were recorded for the FDO. For the RDO, the peak vertical and horizontal accelerations were up to 13.75 ± 2.01 g and 5.75 ± 0.96 g, respectively.

DISCUSSION: The key findings of this pilot study are that horizontal acceleration, particularly at the front dropout, contributes considerably to vibration exposure in gravel biking, and that reducing tire pressure from 3.5 to 1.5 bar decreases vibration exposure by approximately 40%. The rms value of the vertical acceleration of the front dropout was up to 2.65 ± 0.18 g, and peak accelerations due to single impacts were up to 12.64 ± 1.90 g. Compared to a worst-case scenario of riding a road bike on cobblestones at a comparable speed of 20 km/h, the vertical rms of accelerations of the front and rear dropouts on gravel reached up to 43% and 46% of those on cobbles, respectively, depending on the tire pressure (Viellehner & Potthast, 2020).

Decreasing the tire pressure also significantly decreased the rms of vertical and horizontal accelerations at both the front and rear dropouts. The tire pressure adaption from 3.5 bar to 1.5 bar, resulted in a 39% decrease in acceleration at the front dropout and 44% at the rear dropout. This is comparable to the 40% reduction of gravel-induced acceleration at the stem of mountain bikes with a standard air-oil suspension fork compared to a rigid fork (Levy & Smith, 2005).
When comparing horizontal and vertical rms of acceleration, horizontal-to-vertical ratios up to 0.9 were found at the FDO. A similar result was found previously for road-biking on cobblestones, where the rms of the horizontal accelerations at the stem were almost as high as the vertical component (Chiementin et al., 2015).

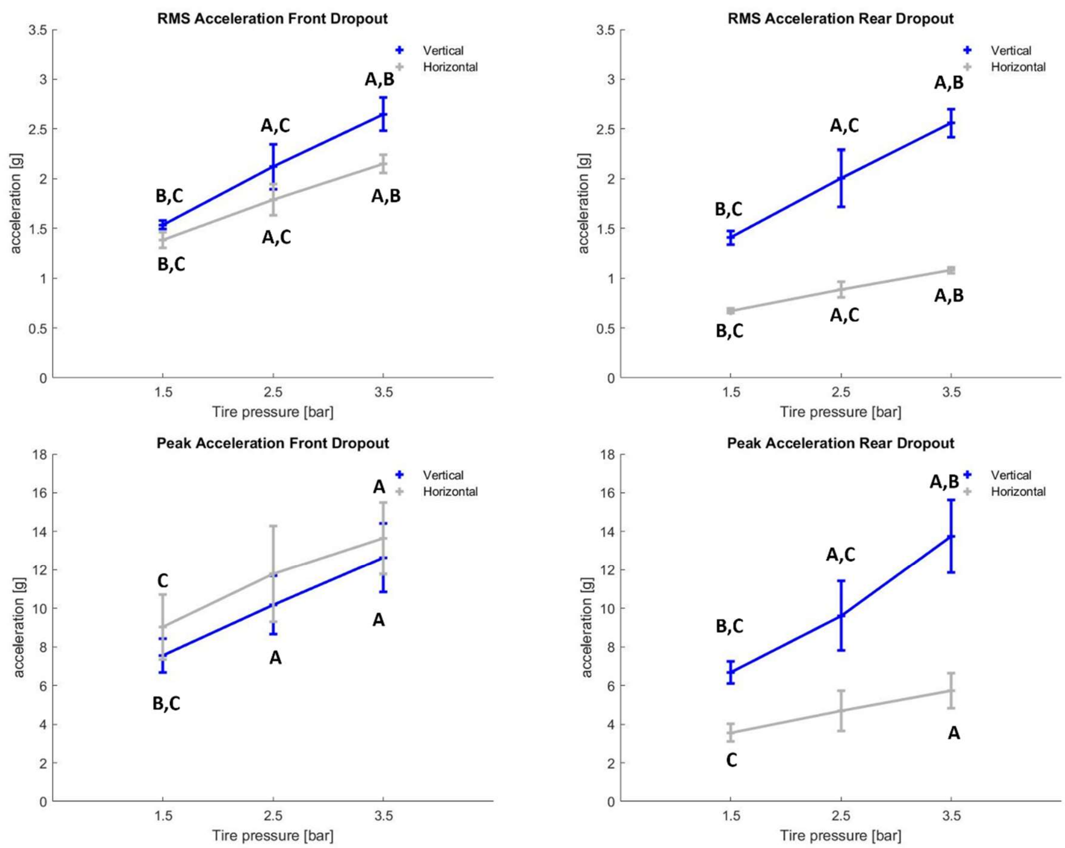

Figure 1: Mean and sd of the rms (top) and peak (bottom) of horizontal and vertical accelerations at FDO (left) and RDO (right) while riding on cobblestones with 25 km/h and 1.5, 2.5, and 3.5 bar tire pressure. 'A': sig. difference between 1.5 and 2.5 bar, 'B': sig. difference between 2.5 and 3.5 bar, 'C': sig. difference between 1.5 and 3.5 bar ($p< 0.05$)

At the RDO horizontal/vertical ratios up to 0.47 are in comparison to the FDO smaller. A possible explanation for the difference in horizontal and vertical acceleration contributions to overall vibration exposure is that the fork of the bike, containing the FDO, has lower horizontal stiffness than the integrated rear dropout. This implies, when the front wheel hits an obstacle, the less stiff fork allows more relative movement of the FDO to the frame than the rigidly integrated rear dropout. To get a deeper understanding of the vibration exposure of the bike, further research is needed looking at frequency analysis and the effects of body weight and speed differences.

CONCLUSION: In summary, these findings indicate that reductions in tire pressure are an effective measure for athletes to manage vibration exposure on gravel, with effects comparable to more complex damping systems as suspension forks. Surface-induced vibrations are not purely a vertical 1D phenomenon, but rather a vertical-horizontal 2D phenomenon in gravel biking. Differences in horizontal and vertical acceleration contributions to overall vibration exposure of FDO and RDO suggest that different specifications for front and rear damping systems are required. Further research is needed to put the effects of e.g. speed, rider weight, tire dimensions or even more subtle tire pressure differences on the vibration exposure of bikes in a broader context.

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ACKNOWLEDGEMENTS: The authors gratefully acknowledge the support and participation of Scott Sports SA, Inc.