UPPER BODY VIBRATION TRANSMISSION IN CYCLING

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This study aimed to identify the effects of vibration frequency on upper body transmissibility in cycling. We hypothesized, that vibrations around 15 Hz are transmitted more intensely to the upper body than vibrations around 45 Hz. The effect of the independent variable vibration frequency on the dependent variable vibration transfer ratio of the torso and the hand-arm system was analysed. Nineteen amateur cyclists (75.1 ± 5.7 kg, 1.78 ± 0.05 m) performed test rides on a racing bike which was mounted on two vibration plates. During the vibration interventions VIB LOW (Front-/ Rear dropout: 17 Hz / 12 Hz), VIB MED (Front-/ Rear dropout: 32 Hz / 27 Hz) and VIB HIGH (Front-/ Rear dropout: 47 Hz / 42 Hz) accelerations at the lower back, neck, hand and acromion were recorded with 3D sensitive accelerometers. Transfer ratios occurred in between 1.82 ± 0.51 from the lower back to the neck for VIB LOW and 0.06 ± 0.03 from the hand to the shoulder for VIB HIGH. The lower back – neck and hand - shoulder transfer ratios decreased from VIB LOW to MED to HIGH significantly, which supports our initial hypothesis. These results suggest that vibrations around/below 15 Hz contribute substantially to upper body vibration exposure in cycling.

KEYWORDS: cycling, vibration, comfort

INTRODUCTION: Gravel bikes extend the application range of road bikes to cycling on easy off-road terrain and unpaved roads. These types of surfaces generate vibrations that have the potential to compromise riding comfort (Chiementin et al., 2013). Since a lower level of vibration is usually associated with superior comfort, one objective of sports technology interventions is to reduce the athlete's exposure to vibration.
Previous cycling-related research described the vibration exposure of the lower extremities (Munera et al., 2018) or the hand-arm system (Chiementin et al., 2013). It demonstrated that damping systems installed under the saddle and handlebars effectively reduce upper body exposure (Viellehner & Potthast, 2020). As vibrations in cycling mainly occur in bandwidth up to 50 Hz, the question arises which frequency bands are of primary interest for further optimize the damping properties of the bicycle and its parts. The transmission ratio of vibrations through the musculoskeletal system represents the biodynamic response of the body in between the point where the vibration is applied, e.g. the hand or lower back at the saddle or handlebar interface, and the point at which the vibration is measured on the body, e.g. the neck. Studies with seated (Griffin, 1975) or standing people (Randall et al., 1997) demonstrated, analogous to the resonance frequencies of the body around 9 - 16 Hz (Randall et al., 1997), that the transmission ratio of vibrations decreases with frequency. In cycling the highest lower extremities transmissibility was found from the pedals to the hip around 20 Hz in a tested range of 20 - 70 Hz (Munera et al., 2018). As vibrations are transmitted to the rider also via handlebars and saddle, transfer ratios for the upper body are also of interest. Therefore, this study aimed to identify the effects of vibration frequency on upper body transmission ratios in cycling. Based on the literature we hypothesized, that the transmissibility of vibrations is higher for low-frequency content around 15 Hz rather than frequencies around 45 Hz.

METHODS: Based on a single group design with repeated measures the effect of the independent variable vibration frequency on the dependent variable transmission ratio of the upper body was analysed. Nineteen healthy amateur cyclists (mass 75.1 ± 5.7 kg, body height 1.78 ± 0.05 m, training volume per year 8315 ± 4936 km, male: 15, female: 4) performed laboratory-based test sessions on a racing bike (Addict RC 20 2021, Scott Sports SA, Givisiez, Switzerland) which was mounted on two vibration plates. After the explanation of testing procedures, each participant gave written informed consent to participate. The experimental

design was approved by the university ethics committee and conformed to the World Medical Association Declaration of Helsinki.
Based on the typical frequency spectrum of surface-induced cycling vibrations (De Lorenzo & Hull, 1999; Viellehner & Potthast, 2020a) three frequency conditions VIB LOW (Front-/ Rear dropout: 17 Hz / 12 Hz), VIB MED (Front-/ Rear dropout: 32 Hz / 27 Hz) and VIB HIGH (Front-/ Rear dropout: 47 Hz / 42 Hz) were defined. The frequency shift of approximately 5 Hz for the front and rear dropout was observed during prior field testing when cycling on cobblestones. This also contributed to a semi-stochastically stimulation that felt more natural to the participants. The initiation of vibrations was done by two vibration plates, which were connected with a rigid interface directly to the bike frames' front and rear dropouts. The resulting accelerations, which were initiated to the bike frame can be found in table 01. Exercise intensity and cadence were controlled with a cycling trainer, which was mounted on the rear vibration plate (Tacx Satori Smart, Tacx, Wassernaar, Netherlands) and a crank-based powermeter (SRM, 5th gen, SRM, Jülich, Germany). After a familiarization period, participants were instructed to maintain a stable cadence of 80 rpm at an exercise intensity of 200 W. Vibration interventions LOW, MED and HIGH took place in randomized order and lasted two minutes each, of which the last 20 seconds were recorded. Participants were equipped with 3D accelerometers (Myon Aktos IMU @ 275 Hz, Schwarzenberg, Switzerland) at the lower back and neck (L1 and C7 vertebrae), hand and the acromion. Signal processing included 6 high-pass filtering (6 Hz, Butterworth, 2nd order) to separate vibration-induced high frequent signal components from voluntary movement-induced low-frequency components. The vibration exposure of the cyclist was calculated as the rms of the resultant acceleration in the x-, y- and z-direction for each accelerometer. The transfer rate of vibration (T) was calculated as follows: $T = RMS_{Out} / RMS_{In}$, with RMS_{In} is being set as the accelerations closer to the vibration source, and RMS_{Out} is defined by the accelerations recorded at the body part further away from the source. One-way repeated-measures ANOVAs were calculated to analyse the effects of vibration frequency (LOW – MED – HIGH) on upper body vibration exposure and vibration transfer rates. Descriptive and inferential statistics were calculated using Matlab (Matlab R2021B, The MathWorks, USA).

RESULTS: Discrete values are presented as means ± standard deviation. The highest accelerations of 9.04 ± 2.09 g were found for the hand-arm system at VIB HIGH (table 1). The lowest vibration exposure was found for the neck at VIB HIGH (0.21 ± 0.06 g).

Table 1: Input acceleration at the vibration plates, vibration exposure of the upper body and transfer rates of accelerations at the torso and the hand-arm system. L indicates significantly different to LOW (p<0.05), M indicates significantly different to MED (p<0.05), H indicates significantly different to HIGH (p<0.05)

Vibration exposure

	Vib Low	Vib Med	Vib High
Input Acceleration Vibration Plate (g)			
Front	1.15 ± 0.08	3.95 ± 0.69	7.48 ± 0.91
Rear	0.78 ± 0.02	2.57 ± 0.15	6.15 ± 0.21
Acceleration Cyclist (g)			
Lower Back	$0.26 \pm 0.03^{M,H}$	$0.57 \pm 0.09^{L,H}$	$0.89 \pm 0.15^{M,L}$
Neck	$0.47 \pm 0.14^{M,H}$	$0.25 \pm 0.06^{L,H}$	$0.21 \pm 0.06^{M,L}$
Shoulder	$0.9 \pm 0.25^{M,H}$	$0.7 \pm 0.33^{L,H}$	$0.52 \pm 0.16^{M,H}$
Hand	$2.41 \pm 0.41^{M,H}$	$7.42 \pm 2.19^{L,H}$	$9.04 \pm 2.09^{M,L}$
Upper Body Transfer Rate			
Lower Back - Neck	$1.82 \pm 0.51^{M,H}$	$0.46 \pm 0.13^{L,H}$	$0.24 \pm 0.07^{L,M}$
Hand - Shoulder	$0.38 \pm 0.12^{M,H}$	$0.1 \pm 0.05^{L,H}$	$0.06 \pm 0.03^{L,M}$

DISCUSSION: The purpose of the study was to analyse the transmissibility of typical vibrations in cycling through the upper body. The main result was that vibrations in the frequency range

around 15 Hz are transmitted more strongly within the torso and hand-arm system than higher frequent vibrations around 30 Hz or 45 Hz.
A similar trend is reported for pedal-hip transfer ratios, which decrease from about 0.06 to approximately 0.02 in between 20 Hz and 60 Hz (Munera et al., 2018). In comparison to previous research, the magnitude of the vibrations introduced into the hand-arm system was comparable to vibrations observed on rough roads (Arpinar-Avsar et al., 2013) and cobblestones (Chiementin et al., 2013). Reference values for vibration exposure of the upper body during road cycling are to the best of our knowledge not published yet. The considerably higher torso transfer quotient at lower frequencies manifested most prominently at the neck. Although the magnitude of acceleration applied by the rear vibration plate was 87% lower with VIB LOW than with VIB HIGH, the vibration exposure of the neck was more than doubled with VIB LOW than with VIB HIGH. A comparable trend was observed for the hand-arm system, respectively, the shoulder. Interestingly, for VIB LOW, accelerations were higher at the neck than at the lower back. This amplification indicates that during VIB LOW there is also a considerable transfer of vibrations from the hand-arm system to the neck. Although damping elements in the bike were not considered in the study, our results support the idea that in the VIB LOW frequency range not only saddle damping but also handlebar damping can potentially contribute to a reduced vibration exposure of the neck and head. Anecdotal feedback suggests that the VIB LOW intervention, despite the low absolute magnitude of vibrations, was perceived as very uncomfortable especially, at the head. However, a systematic classification of how the magnitude of the vibrations at the body segments influences the perceived comfort is still pending. In this first step, the focus of this study was on a basic understanding of the vibration exposure of the upper body. A consequential limitation was that for a controlled input, uniform oscillations at discrete frequencies were applied. The use of stochastic vibration signals that represent a complete spectrum is a logical next step towards improved ecological validity. Future perspectives include also the analysis of vibration transmission at the bike-human interfaces handlebar and saddle and the categorisation of local vibration exposures and its subjective perception, concerning its relevance for the overall riding comfort.

CONCLUSION: To the best of our knowledge, this study is the first to investigate vibration exposure of the upper body at different frequencies within the spectrum typical for cycling. The results suggest that vibrations around 15 Hz contribute substantially to upper body vibration exposure in cycling. One focus of damping systems for gravel bikes should be on the reduction of vibrations around or smaller than 15 Hz. In this frequency band, decoupling both the handlebars and the saddle seems to make sense for effective vibration reduction at the head.

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