ACCELERATION TRANSMITTED TO THE HUMAN BODY DURING CYCLING: EFFECT OF A ROAD BIKE DAMPING SYSTEM

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The objective of this study was to examine the influence of a road bike damping system on accelerations transmitted to the cyclist. Thirty male subjects performed trials with and without vibration on a damped and non-damped road racing bike at three different power level. Three-dimensional accelerations at thigh, shank, lower back, acromion, neck and forearm were recorded to quantify the athlete-bike interaction. Vibrations were found to effect the entire body significantly. Significant differences regarding the damped and non-damped bike were observed for the vibrations transmitted to the upper body, while lower extremity loading was comparable. Therefore road bike damping reduces mechanical load at the upper extremities and torso effectively and thereby possibly contributes to comfort and injury prevention. This might provide beneficial information to coaches and athletes for material selection.

KEYWORDS: cycling, vibration, acceleration transmission

INTRODUCTION: In road cycling equipment has a huge effect on the athletes comfort and performance. While in the past weight and stiffness of the bikes have been a key concern, evolving designs and materials allow to modify the vertical stiffness of the bike and thereby filter vibrations caused by bumpy roads. Surface induced vibrations in cycling are linked not only to cause discomfort, but also to result in pain at the hand-arm system or traumatisms at the back (Schwellnus & Derman, 2005). Although findings for the effects on muscular activity, (Munera, Bertucci, Duc & Chiementin, 2018; Srinivasan & Balasubramanian, 2007), muscular metabolism (Filingeri, Jemni, Bianco, Zeinstra & Jimenez, 2012; Mester, Spitzenfeil, Schwarzer & Seifriz, 1999), and cardiopulmonary response (Filingeri et al., 2012; Munera et al., 2018; Sperlich, Kleinoeder, Marées, Quarz, Linville & Haegele, 2009) are not entirely homogenous, vibration eventually also causes an performance decrease in cycling. It has been demonstrated, that technical modifications, as frame characteristics, or seatpost suspension can modify the dynamic response of the bike, which might consequently help to increase comfort or enhance performance (Giubilato & Petrone, 2012; Parkin & Saint Clauque, 2014). A very recent approach for the damping of surface induced accelerations is a bike design based on a 20 mm damping unit in between frame and stem (Futureshock, Specialized USA) and a seat post design which implements a reduced vertical and reduced anterior posterior stiffness.

With the exception of Munera and colleagues (Munera et al., 2018), who measured accelerations at the lower limb, the large majority of the studies focused their attention on the dynamic response measured at different points of the bicycle. However, none of them recorded the vibrational response at the human body. The purpose of the current study is to describe effect of a road bike specific damping system on the dynamic response of the human body when performing pedalling exercises at various power level, with and without cycling specific vibration applied.

METHODS: A cross-sectional single cohort study was used to identify the effects of damped versus non-damped road racing bikes on transmitted cycling specific acceleration. 30 trained amateur cyclists (75.9 ± 8.9 kg, 1.82 ± 0.05 m, Vo2max: 63 ± 6.8 ml/min/kg) performed on two testing days two-minute test rides at individually scaled power levels (40%, 60% of maximum

oxygen consumption and individual 4 min maximum) with and without vibration on a damped ('D') (Specialized Roubaix Comp) and non-damped ('ND') road bike (Specialized Tarmac SL5 Expert). Cycling specific vibration characteristics were defined previously. Therefore six subjects performed outdoor test rides on cobblestones. Vertical accelerations were recorded over 15 s at the front and rear dropout with custom made acceleration sensors (German Sports University, GER , +/- 50 g, 6 kHz).
Based on this, vibration settings for the laboratory were set separately for front- and rear wheel at 44 Hz, respectively 38 Hz median frequency and a root mean squared vertical amplitude of 4.1 mm, respectively 3.5 mm. Two vibratory platforms (Netter Vibration, VTE 5/5 – 2NEG 50300) were used to applicate the external vibrations directly at front-, respectively rear dropout. A cycle ergometer (Tacx Satori Smart, Tacx, Wassernaar, Netherlands), mounted on the posterior platform, ensured the fixation of the rear wheel and provided the desired resistance. Power was controlled with a crank based powermeter (SRM 5th Gen, SRM, Jülich, GER). Subjects were equipped with six skin mounted IMU sensors (Aktos-T, Myon, Schwarzenberg, CH, 2000 Hz) attached at medial distal shank, medial distal thigh, lower back on the height of L5, acromion, neck on the height of C7 and mid forearm. They were asked to keep a standardized hand position at the brakehoods while pedaling with 80 - 90 rpm at their individually set power levels (Pow_Low: 137 ± 14 W, Pow_Med: 221 ± 18 W, Pow_High: 331 ± 65 W). Each condition was performed with ('Vib') and without ('No-Vib') vibration. Three dimensional acceleration signals were recorded over 20 seconds, filtered with a recursive 2nd order 5 Hz high pass Butterworth filter. This allowed the separation of acceleration components caused by voluntary movement and a purely vibrational induced higher frequent component. According to ISO standards (ISO2631 and ISO539) root mean squared acceleration describes the perception of vibration. A two-way repeated-measures ANOVAs was used to identify effects of vibration and bike damping. Descriptive and inferential statistics were conducted using Matlab (Matlab R2016B, The MathWorks, USA).

RESULTS: Acceleration magnitudes are visualized in Figure 1. Discrete values are presented in Table 1. Values are expressed in [g] (earth gravitational constant).
A two way repeated measures ANOVA was run to determine the effect of road bike damping with and without superimposed vibrations on perceived accelerations at thigh, shank, pelvic, shoulder, neck and forearm. There was a statistically significant interaction of vibration and damping ($p < 0.05$) on perceived acceleration. Therefore simple main effects were calculated.

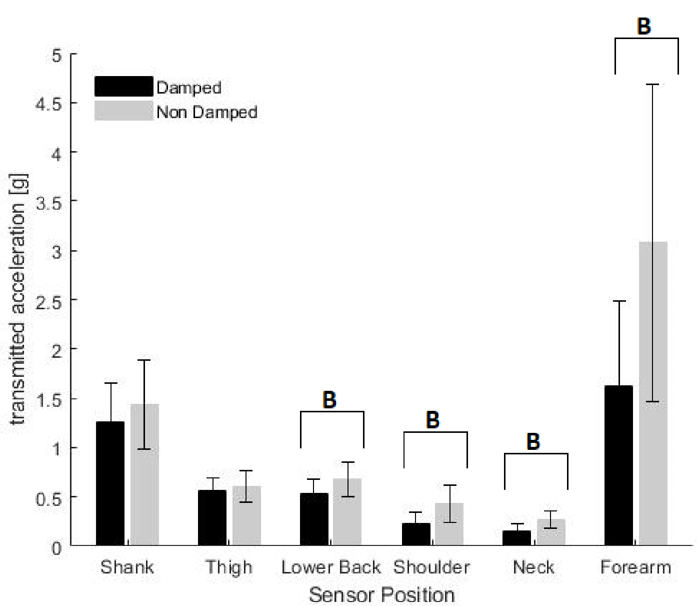

Figure 1: Exemplary visualization of resultant acceleration during vibration at medium power level for the damped and non-damped bike. 'B' indicates a bike specific difference in between damped and non-damped during vibration (p< 0.05)

During the No-Vib conditions, at all body segments local accelerations were comparable. Inversely superimposed vibration resulted in significantly higher accelerations compared to the No-Vib conditions, at all power level and in each body part. Acceleration at shank and thigh did not differ significantly for the damped and non-damped bike during vibration. Opposite to this, significantly decreased accelerations at the pelvic, acromion, neck and arm were found for the damped bike.

Table 1: Resultant acceleration [g] over 20 seconds at shank, thigh, pelvic, shoulder, neck and forearm. 'V' indicates significant differences (p < 0.05) in between 'Vib' and 'NoVib'. 'B' indicates a difference in between D an ND bike during vibration (p< 0.05)

Sensor Position	Bike : Vibration	Low_Power mean ± sd acc [g]		Medium_Power mean ± sd acc [g]		High_Power mean ± sd acc [g]	
Forearm	D_NoVib	0.06 ± 0.01		0.07 ± 0.01		0.1 ± 0.02	
	D_Vib	1.51 ± 0.59	BV	1.62 ± 0.87	BV	1.67 ± 0.74	BV
	ND_NoVib	0.05 ± 0.01		0.06 ± 0.01		0.09 ± 0.02	
	ND_Vib	3.17 ± 1.39	V	3.08 ± 1.61	V	3.38 ± 1.59	V
Neck	D_NoVib	0.03 ± 0.01		0.04 ± 0.01		0.06 ± 0.02	
	D_Vib	0.18 ± 0.06	BV	0.15 ± 0.07	BV	0.15 ± 0.06	BV
	ND_NoVib	0.04 ± 0.01		0.04 ± 0.01		0.06 ± 0.01	
	ND_Vib	0.31 ± 0.13	V	0.27 ± 0.09	V	0.2 ± 0.06	V
Lower Back	D_NoVib	0.03 ± 0.01		0.04 ± 0.01		0.06 ± 0.02	
	D_Vib	0.54 ± 0.14	BV	0.53 ± 0.15	BV	0.47 ± 0.1	BV
	ND_NoVib	0.04 ± 0.01		0.04 ± 0.01		0.06 ± 0.02	
	ND_Vib	0.74 ± 0.21	V	0.68 ± 0.18	V	0.59 ± 0.14	V
Shank	D_NoVib	0.21 ± 0.05		0.23 ± 0.05		0.3 ± 0.06	
	D_Vib	1.13 ± 0.27	V	1.26 ± 0.39	V	1.46 ± 0.43	V
	ND_NoVib	0.23 ± 0.05		0.23 ± 0.05		0.31 ± 0.06	
	ND_Vib	1.26 ± 0.4	V	1.44 ± 0.45	V	1.66 ± 0.49	V
Acromion	D_NoVib	0.04 ± 0.01		0.05 ± 0.01		0.07 ± 0.02	
	D_Vib	0.28 ± 0.15	BV	0.23 ± 0.11	BV	0.25 ± 0.11	BV
	ND_NoVib	0.04 ± 0.01		0.05 ± 0.01		0.07 ± 0.02	
	ND_Vib	0.46 ± 0.21	V	0.43 ± 0.19	V	0.4 ± 0.15	V
Thigh	D_NoVib	0.15 ± 0.04		0.18 ± 0.05		0.24 ± 0.06	
	D_Vib	0.54 ± 0.13	V	0.56 ± 0.13	V	0.63 ± 0.15	V
	ND_NoVib	0.15 ± 0.04		0.18 ± 0.04		0.24 ± 0.05	
	ND_Vib	0.55 ± 0.15	V	0.6 ± 0.16	V	0.67 ± 0.13	V

Discussion: Comparable accelerations for all body segments while pedalling without superimposed vibration demonstrates for both bikes a similar behaviour on smooth surfaces. Increased accelerations at all vib test conditions implicate that surface induced vibrations are a systemic phenomenon, which changes the mechanical load for the entire body. A vibration induced increase in muscular activation, as found for the lower extremities (Munera et al., 2018) seems thereby also to be reasonable for the stabilizing muscles at the trunk and upper

extremities. This may reflect in increased metabolic demands during vibration (Filingeri et al., 2012; Sperlich et al., 2012).
Taking under consideration the bicycle construction, where the crank is typically not decoupled from the frame, an analogous acceleration transmission to the pedals and lower extremities for D and ND bike is reasonable. Comparable accelerations at thigh and shank for both bikes provide strong evidence, that the mechanical loading of the main propulsive muscles as e.g. musculus quadriceps femoris is not effected by road bike damping. Contrary to this, damping decreases accelerations effectively at the upper body and thereby might help to avoid overuse injuries (Schwellnus & Derman, 2005). Further research is needed to clarify, if the damping related load removal of the upper body reflects in reduced metabolic costs.
A potential stiffening of the upper body or position change on the bike due to increased power showed no effect on the observed pattern of reduced accelerations for the upper body and comparable loading for the lower extremities. Thus damping is expected to have an effect not only for recreational cyclists, but also for competitive riders during phases with high power output. Further research regarding metabolic costs, kinematics, muscular activation or joint loading is necessary for a deeper understanding of the rider bike interaction during vibration.

CONCLUSION: Transmission of vibration in cycling to the athlete is a complex phenomenon due to multiple insertion points and nonlinearities in the athlete's musculoskeletal system. This study described the effect of a road bike specific damping system on transmitted accelerations to the cyclist. While no effect was found on lower extremity loading, road bike damping reduces accelerations at the upper extremities and torso effectively and thereby possibly contributes to comfort and injury prevention. This might provide beneficial information to coaches and athletes for material selection. Further research is needed to clarify, if a decrease in mechanical loading not only influences riding comfort but also lowers metabolic costs and thereby enhances performance.

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