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The influence of pelvic-belt design on backpack stability in mountain-biking

Lucas Höschler [1,2], Michael Frisch [2] and Frank I Michel [1]*

1 VAUDE Sport GmbH & Co. KG, i-team, Tettnang, Germany
2 University of Bayreuth, Institute for Sport Sciences, Bayreuth, Germany

* Correspondence: Frank I. Michel. frank.michel@vaude.com

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1. Introduction

Among other factors the backpack stability is determining the comfort of bike backpacks. In mountain biking, especially in downhill passages, large vibrations occur (Macdermid, Fink & Stannard, 2014) that get transferred to the rider and cause undesired backpack wobbling, which can disturb rider's balance. The pelvic belt is commonly attributed to provide the necessary stability and is therefore a common feature amongst most modern bike backpacks (Frey, 2019). Recent research show that a pelvic belt partly reduces the backpack wobbling while mountain biking (Höschler, Michel & Frisch, 2021), but is not needed for stabilization when road cycling (Campos, Timm, Michel & Bankay, 2020). These findings could change the design of bike backpacks because a pelvic belt is only needed for those biking activities where heavy impacts are expected. Bike backpacks worn by commuters and occasional mountain bikers incorporate a pelvic belt that is not only rarely needed but presumably also lowers the thermal comfort due to a thick padding in the pelvic region. A potential innovation could be the development of a roll-up belt, that can be fastened when needed and easily rolls up in the backpack (Fig. 1, patent pending). In order to develop a functional roll-up belt the influence of basic belt characteristics such as elastic properties, retraction force and contact area on backpack stability must be determined.

The goals of this study were to compare the effect of different pelvic belts on backpack stability in mountain biking, to test the potential of roll-up belts and to derive findings for further backpack development.

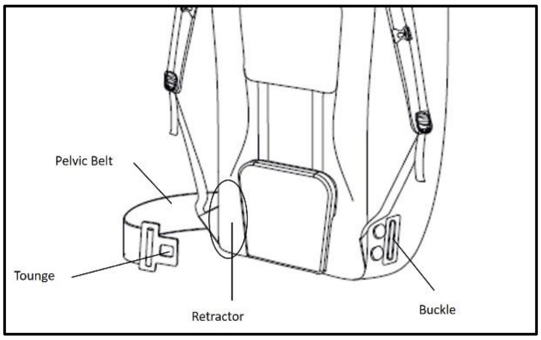

Figure 1. Draft of a roll-up pelvic belt incorporating a belt with tongue, a buckle and a retractor integrated in the backpack.

2. Materials and Methods

Three models of a conventional bike backpack (VAUDE Ledro 18 L) were modified. Therefore, the original belts were removed and substituted. One modified belt consisted of two elastic bands (width 50 mm) connected by Velcro (EB, Fig. 2 a). The two other backpacks were modified with roll-up belts by integrating the belt retractor and anchorage in the side pockets of the backpacks. One model was equipped with a conventional seatbelt (SB, width 47 mm, DIN EN ISO 6683) with an auto-block mechanism (SB, Fig. 2 b). For the other a spring balancer with thin cord (diameter 2 mm, MOLEX) and adjustable retraction force (set to 5 and 20 N) was used (SPRING5; SPRING20, Fig. 2 c). An unmodified bike backpack (VAUDE Moab II 16L) with a conventional pelvic belt was used for comparison (CB, Fig. 2 d). All backpacks were filled and loaded with 4 kg additional weight.

Figure 2. Belt conditions: (**a**) Elastic Band (EB), (**b**) Seatbelt (SB), (**c**) Spring balancer (SPRING5 & SPRING20), (**d**) Conventional Belt (CB).

The influence of the different belts on backpack stability was tested with 11 healthy, male recreational cyclists (age 35.8 ± 8.3 years, height 180 ± 4 cm, mass 72.8 ± 5.7 kg, training workload 228 ± 196 km/month). They used a 29” hard-tail MTB (Centurion Backfire) to ride over an uneven ramp (length 2.5 m, height 0.3 m) while wearing the different belts (Fig. 3). No instructions were giving on riding technique. Triaxial IMUs (sampling frequency 2000 Hz, Myon Aktos) were used to measure the accelerations of rider and backpack during 5 trials. Two of them were placed on the spine at the height of the 7th crevicular vertebra (C7) and the 2nd sacral vertebra (SACRUM). Two corresponding IMUs were fixed inside the backpack at the upper (TOP) and lower end (BOTTOM) of the back plate.

A script written in Matlab R2020a (The MathWorks, Natick, USA) was used for data analysis. 3D- accelerometer data was filtered with a 2nd order Butterworth filter at 10 Hz and used to calculate the resultant acceleration. The regional backpack wobbling (BPW) was calculated as the ratio between the integrated acceleration of the backpack segment and the corresponding body position (TOP/C7, BOTTOM/SACRUM) averaged over 5 trials. For statistical analysis, the paired t-test ($p=0.05$) was used after normality had been proven by the Shapiro–Wilk test.

All trials were filmed from a sagittal view (resolution 1024p, 30 fps) to visualize the backpack displacements (Fig. 4). Subjective feedback regarding backpack wobbling and overall comfort was provided with a standardized questionnaire.

Figure 3. Experimental set-up: Subject biking over the ramp.

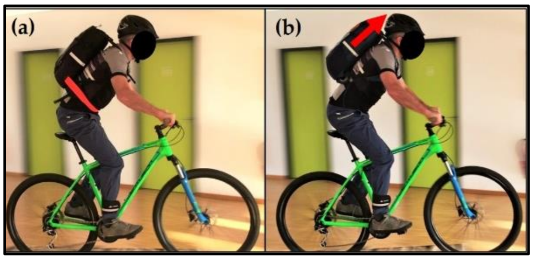

Figure 4. Sagittal view of two belt conditions: (**a**) Seatbelt, (**b**) Elastic band.

3. Results

No significant differences were found between the belts for the BPW at the top region. Regarding the bottom region, the CB condition had significantly smaller BPW values than EB ($p=0.003$), SB ($p=0.011$), SPRING5 ($p=0.002$) and SPRING20 ($p=0.001$). Out of the roll-up belts, SB showed less BPW in the bottom region than SPRING5 ($p=0.035$) and SPRING20 ($p=0.036$). There were no significant differences between the two spring forces ($p=0.489$) (Fig. 5). The subjective perception of the backpack wobbling was mostly in good agreement with the measured values (Fig. 6).

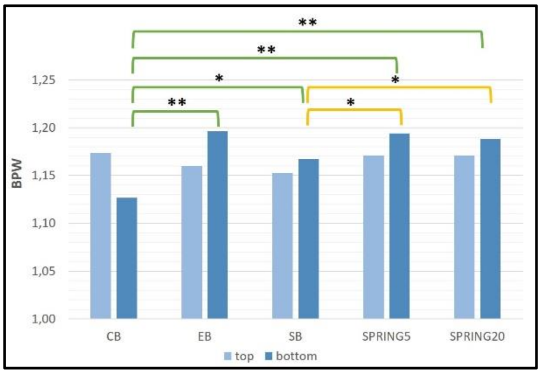

Figure 5. Regional Backpack Wobbling (BPW) of the different belts. Conventional belt (CB), elastic band (EB), seatbelt (SB), spring balancer at 5 and 20 N (SPRING5, SPRING20). * $p < 0.05$, ** $p < 0.01$.

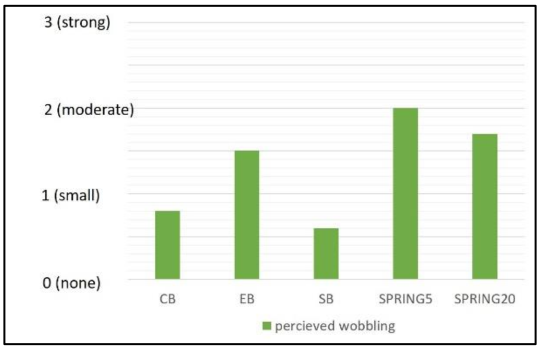

Figure 6. Perceived backpack wobbling.

4. Discussion

The modified belts used in this study could not stabilize the backpack to the same amount as the conventional belt. In agreement with previous findings the backpack stability in the top region was not influenced by any of the pelvic belts (Höschler et al., 2021).

The higher BPW of the EB compared to the CB condition indicates that belts made of elastic material do not provide adequate stability for mountain biking. Pelvic belts should be manufactured of somewhat stiff material or use a combination of stiff and elastic materials. However, the feedback on perceived wobbling and the overall comfort was positive, especially regarding unhindered abdominal respiration, so the development of more elastic belts should be considered.

Comparing the different roll-up belts, the seat belt provided a greater wobbling reduction than the spring balancer presumably caused by the larger contact area, frictional properties, or the blocking mechanism of the seat belt. No differences in stability were found between the two spring forces, indicating that there is no increase in stability with higher strap forces for thin belts.

The differences between subjective and measured wobbling can be explained by the variety of riding styles between the subjects. The direction of the backpack displacement was primarily vertical (Fig. 4). This highlights the importance of a sufficiently stabilized backpack when mountain biking. A functional pelvic belt will prevent the backpack from hitting the head and disturbing rider's balance (Frey, 2019).

Subjects reported a low overall comfort caused by continuous blocking and abdominal compression of the SB. The spring balancer was assessed more positively for being inconspicuous and barely noticeable, yet the perceived wobbling was higher. This highlights the importance of both, subjective feedback and biomechanical analysis for backpack research. If further improved towards comfort for SB or towards stability for the spring balancer, roll-up belts could be an innovative feature for bike backpacks by providing some degree for stability when mountain biking and being easily hidden when cycling on road or gravel.

Future studies should focus on understanding the role friction plays on backpack stability and compare the thermal comfort of different pelvic belts. Roll-up belts are a promising feature for bike backpacks and should be developed further.

5. Practical Applications

The most important findings about the function of the pelvic belt are summarized below. They increase the scientific knowledge and can help manufacturers to further improve bike backpacks.

- The pelvic belt has no load bearing function in a sportive riding position, making excessive padding unnecessary (Timm, Campos & Michel, 2020).
- The pelvic belt stabilizes the bottom but not the top region of the backpack when mountain biking, leaving room for an improved design of shoulder and chest straps (Höschler et al., 2021).
- The main backpack displacement when mountain biking is in vertical direction, followed by the anterior-posterior displacement of the bottom region.
- The pelvic belt does not stabilize the backpack in the stand-up or brake-hood position when road cycling, showing the possibility of a reduced belt for those applications (Campos et al., 2020).
- Continuous abdominal compression by the belt restricts respiration, possibly reduces performance, causes discomfort, and should be avoided.
- Elastic belt materials do not provide sufficient backpack stability for mountain biking but are perceived comfortable.
- Besides belt tension, friction plays a large role on backpack stability.
- Individual preferences and subjective perception can differ from biomechanical measurements and should be respected.

If further improved, an ideal roll-up belt would be advantageous with regards to adjustable backpack stability, unhindered abdominal respiration, improved thermal comfort and ergonomics.

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Conflicts of Interest: The authors declare no conflict of interest.

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