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Effect of shoulder strap design and mechanical properties on the surface pressure of bike backpacks

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Abstract: For a number of reasons, comfort of bike backpacks is increasingly important. Considering the long-term effect, discomfort can lead to severe injuries or at least pain especially in the shoulder region. An alternative to subject studies is the determination of discomfort by detecting the surface pressure. However, until today there is no previous study which investigated the comfort or the surface pressure in bike backpacks. The aim of the present study was to evaluate the effect of shoulder strap design and material properties in bike backpacks on surface pressure. Fourteen healthy male subjects carried 6 different backpack configurations while cycling on a stationary bicycle in brakehood position. The backpack configurations differed in shape and padding material at the shoulder strap. The surface pressure was measured with a piezoelectric pressure mapping system. The results revealed that shoulder strap design as well as the material properties could affect the average and peak surface pressure. The modified strap shape showed a significant lower average and peak surface pressure compared to the original backpack. In addition, it has been shown that the use of a relatively stiff PE material in combination with a soft foam as a double layer padding can lead to a significant decrease in average surface pressure compared to shoulder straps with common foam padding or mesh.

Keywords: cycling; backpack; surface pressure; comfort; shoulder strap; material properties

1. Introduction

Beside the growing health consciousness, cycling is enjoying growing popularity based on a new environmental awareness. Therefore, the load transport on bicycles is gaining in importance. In addition to pannier bags, backpacks are a simple and functional alternative. A crucial prerequisite for wearing a backpack is absence of discomfort. With increasing loads and wearing time, mechanical discomfort can cause pain and serious medical issues like the damage of the brachial plexus (Knapik, Harman & Reynolds, 1996). Due to the specific anatomy, the shoulder region is particularly sensitive for the development of injuries. Recent studies showed that 43 % - 67 % of pain caused by backpacks occur in the shoulder and neck region (Dockrell, Kane & O`Keeffe, 2006). According to Wettenschwiler (2016), the surface pressure between subject and backpack is a valid and quantifiable predictor to investigate mechanical discomfort during load carriage. Furthermore, Hadid et al. (2018) investigated the effect of shoulder strap design and material properties on surface pressure on the shoulder region. The modified medialized shoulder strap course caused a pressure redistribution at the shoulder region with decrease peak and average pressure particularly sensitive region of the brachial plexus. The study also showed the positive effect of a double layer padding material with soft foam as outer layer and a stiff inner backbone on the surface pressure. However, all studies which determined the contact pressure to predict discomfort used military or trekking backpacks with payload between 15 kg - 45 kg while walking (Fergenbaum, 2007). Because of the differences in trunk angle and payload, the results of these studies cannot be undertaken unrestricted for bike backpacks. The aim of the present study was to quantitatively characterize the effect of shoulder strap body surface pressure in relation to the sitting position while cycling.

2. Materials and Methods

The subject population consisted of healthy recreational cyclists without prior injuries in the back and shoulder region and with the following anthropometrics: n=14 (14♂), age 36.2 ± 9.1 years, bodyweight 77.9 ± 7.3 kg, height 180.2 ± 2.5 cm. All subjects provided written, informed consent.

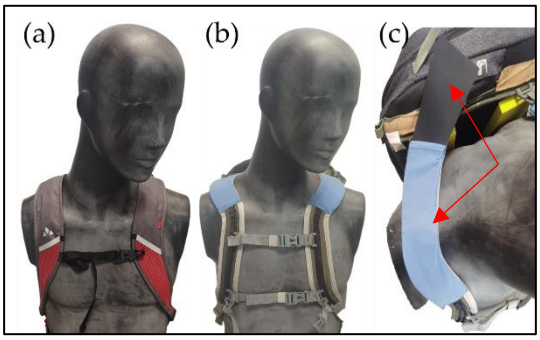

Figure 1. Original shaped shoulder strap (a), medialized shoulder strap (b), insert for PE-layer (c).

The load carriage system applied in this study is a commercially available bike backpack (VAUDE Bracket 22 l; REF) with a payload of 4 kg. Two modifications were made to the system for this study. Firstly, the original shoulder straps were replaced by modified medialized straps similar to Hadid et al. (2018) to decrease and redistribute the pressure and generate more freedom of movement in the shoulder region (Fig. 1 a, b).

Table 1. Dimensions of padding material used for the comparison of different shoulder strap designs (medialization).

Configuration	Strap width	Padding width
Ref	6mm	4mm
EVA	6mm	6mm

Secondly, different padding materials were fastened with Velcro at the modified shoulder strap (EVA similar to the original backpack and Poron with rather viscous properties used for shock absorption in protectors) (Table 2). In addition, stiff 1 mm polyethylen-sheets (PE) were inserted at the acromial area of the shoulder strap to create a double layer padding to reduce the surface pressure (Fig. 1 c).

Table 2. Padding material in combination with 1mm PE-sheet to build a double layer.

Config.	Thickness	Material
Ref	10mm + 2mm	EVA
EVA	10mm + 2mm	EVA
Poron	12mm + 2mm	Poron
Poron 1	12mm + 2mm +1mm	Poron+PE
Mesh	2mm	Mesh
Mesh 1	2mm + 1mm	Mesh+PE

Six backpack configurations were compared based on the same load carriage system to eliminate potential effects of other (not controlled) design variables on discomfort.
A pressure mapping system (Tactilus, Sensor Products Inc.) with a senor size of 2 cm² was adjusted at the shoulder of the subjects to detect the surface pressure. For all measurements, the subjects had to cycle in the brake-hood position for 30 seconds with an estimated back angle of 50° on a stationary bicycle (Fig. 2). All load carriage system configurations were applied in a randomized order. The average pressure (Pmean) and the peak pressure was calculated with Matlab

(R2018b, The MathWorks Inc.).

Figure 2. Experimental design with subject in brakehood position wearing original Bracket 22l.

Data of each parameter was checked for normality (Shapiro-Wilk-Test) and group differences were investigated by a paired sample t-test. Significance was defined at $p < 0.05$ (*) and $p < 0.01$ (**).

3. Results

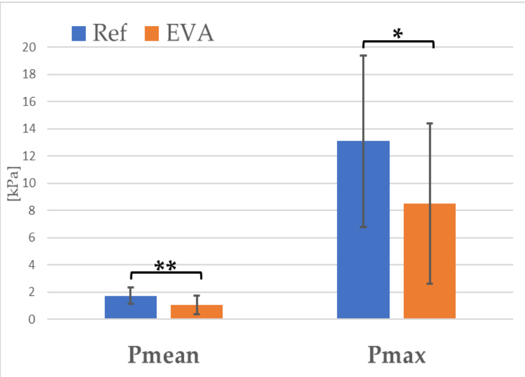

Figure 3. Average surface pressure (Pmean) and peak pressure (Pmax) for backpack condition Ref and EVA (modified shoulder strap design) (n=14).

The modified design shoulder strap course showed a significant lower average pressure at the shoulder region (p=0,005). Furthermore, the peak pressure was significant reduced (p=0,041) (Fig.3).

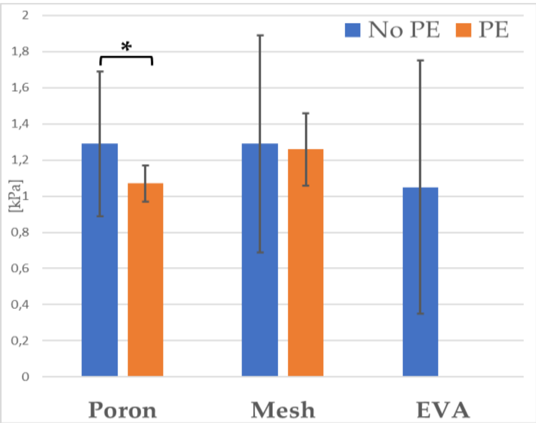

Figure 4. Comparison of average pressure for different padding materials (Poron, Rogers Corporation, Type XRD; EVA and mesh) with and without PE backbone (n=14).

No significant differences were found in average pressure between the single layer shoulder paddings (Poron, Mesh and EVA). Interestingly, there was also no significant difference between the 2 mm Mesh shoulder straps and the straps with 10 mm EVA and 12 mm Poron padding. The double layer padding made up of Poron and PE showed a significant smaller average pressure than the single Poron layer. No significant effect was found between the single layer and double layer paddings made from mesh for the average and peak pressure.

4. Discussion

To our best knowledge, this study was the first to investigate the pressure distribution and surface pressure of bike backpacks. The decreased average and peak pressures at the shoulder region caused by the medialized shoulder strap course coincide with the findings of Hadid et al. (2018), although they used heavier payloads and a different trunk angle. However the effect of the different padding width can't be ruled out (Golriz, Hebert, Bo, Foreman & Walker, 2017), the lower average and peak pressures indicate that the modified shoulder strap design leads to a stress reduction in the sensitive shoulder region and therefore help to reduce pain and injuries.
Comparing the different material properties, the significant lower average pressure shows a positive effect of a soft padding as an outer layer in combination with a stiff material as a load distributor. These results accord to the findings of Hadid et al. (2018) as well. The lack of significance in the comparison of "Mesh" shoulder strap with and without PE-supplement indicate that the positive effect of a stiff backbone (PE-sheet) occurs only in combination with a soft outer layer. Another interesting observation is the absence of significant differences between the shoulder strap conditions with a thick soft padding (EVA, Poron) and the condition without soft padding (Mesh). These findings demonstrate that the shoulder strap design, padding width and combination of materials is more important than the thickness and properties of a single soft padding layer. This is valid at least for bike backpacks of about 4 kg payload and cycling in a sportive seating position (trunk angle of approx. 45-70°.

5. Practical Applications

The most important findings about the effect of shoulder strap designs and material properties are summarized below. They increase the scientific knowledge and can help manufacturers to further improve bike backpacks.

- The medialized shoulder strap design leads to decreased surface pressure and therefore can improve comfort and prevent injuries.
- The medialized shoulder strap course bypasses the brachial plexus area and redistributes the pressure to more bony structures at the shoulder (Hadid et al., 2018).
- The medialized shoulder strap course provides and ensures sufficient freedom of movement around shoulder.
- The stiff backbone of the double layer padding material only has a positive effect in combination with a soft outer layer.
- For a payload of 4 kg, the width of the shoulder strap has a bigger effect on the surface pressure than the material properties of a single layer padding.
- It seems, that for backpacks with a payload below 4kg additional padding does not provide additional comfort in terms of a better pressure pattern. This could be beneficial for lightweight backpacks.
- Based on the present results, padding materials with more viscous material characteristics (compared to conventional EVA) does not generate a better pressure pattern.

As already mentioned above, these findings serve as a starting groundwork in "bike backpack research" to improve the mechanical comfort. There are many more variables which should be investigated systematically like the upper shoulder strap attachment location in terms of distance (shoulder length/width) and shoulder angle as well.

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

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