Deutsche Sporthochschule Köln
German Sport University Cologne

Empa
Materials Science and Technology

VAUDE
The Spirit of Mountain Sports

# Load distribution between upper body and pelvis in different load carriage systems

Sven Paldauf[1], Rolf Stämpfli[2], Frank Emrich[1], Florian Schmid[3], Frank I. Michel[3]

[1] German Sports University Cologne, Germany, [2] Empa, Swiss Federal Laboratories for Materials Science and Technology, Switzerland
[3] VAUDE Sport GmbH &Co. KG, ***i***-team, Germany

## Introduction

Load carriage systems (LCS) are an efficient way to carry load over a long distance and time. But carrying heavy external loads may also cause several injuries (Knapik et al., 2004). A **shift of the load** from the upper body **to the pelvis** via hip belt can lead to a relief of strain and consequently to an increase in comfort and a lower prevalence of injuries (Knapik et al., 2004).

Only a few studies investigated the load distribution between upper body and pelvis and focused mainly on **heavy load carriage in military context** (up to 40 kg). Studies conducted by LaFiandra et al. (2004) and Grawe (2014) calculated the proportion of load distribution for heavy backpacks using subject investigations and computer models, respectively. Consistent proportions of load distribution between the upper body (80 and 70%) and pelvis (30 and 20%) were found, independent of mass. Reid et al. (2006) compared different backpack stay configurations via an instrumented dummy and found proportions of approximately **40% for the upper body** and **60% for the pelvis**. Without stays, approximately 30% of the load was carried by the pelvis. Popular sources recommend shifting more than 70% of the load to the pelvis in trekking as well as hiking activities.

Due to the lack of scientific investigations dealing with the **load distribution of recreational trekking and hiking backpacks** and its importance to prevent injuries, this study aims to investigate the distribution of the vertical load in different backpacks with low pack weight to improve wearing comfort of LCS.

## Material & Methods

All measurements were performed using the **instrumented dummy** described and validated by Wettenschwiler et al. (2017). A horizontal division of the dummy at the height of the L4 vertebra enabled a **measurement of the vertical load** [N] on the upper body and the pelvis. Two load cells with six degrees of freedom were attached inside the torso above and beneath the segmentation, respectively. The torso was aligned in an upright position without inclination. A **tensiometer** based on strain gauges was used to **standardize** the strap forces in the shoulder straps and the hip belt within groups. Finally, the **relative load distribution** was calculated retrospectively.

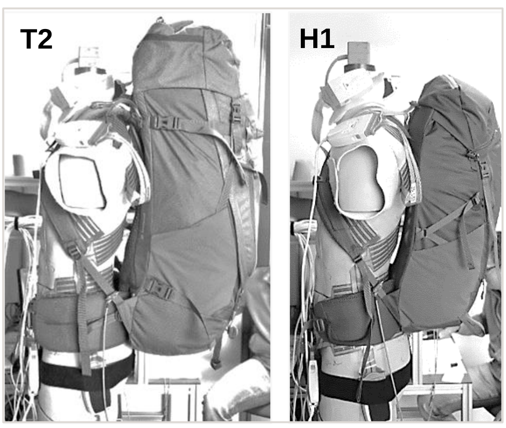


**Fig. 1:** Exemplary backpack mounting on the dummy

Two backpack categories, each furnished with a hip belt, were analysed (Fig. 1):

The **trekking category** (**TG**) included two trekking backpacks (T1, T2) of **12 kg** filling weight, **60 l** backpack volume and an internal frame which is characterized by a rigid connection between shoulder straps and hip belt.

The **hiking category** (**HG**) included two hiking backpacks (H1, H2) with a filling weight of **6 kg**, a lower volume (**30 l**) and a less rigid connection between shoulder straps and hip belt (back panel).

## Results

A load distribution of approximately **70%** carried by the **pelvis** and **30%** by the **upper body** was found in the **TG**. The **HG** exposed an **inverted load distribution**. Additionally, the absolute vertical load on the upper body was higher for both LCS in the HG although the absolute backpack mass was around 50% lower (Fig. 2).

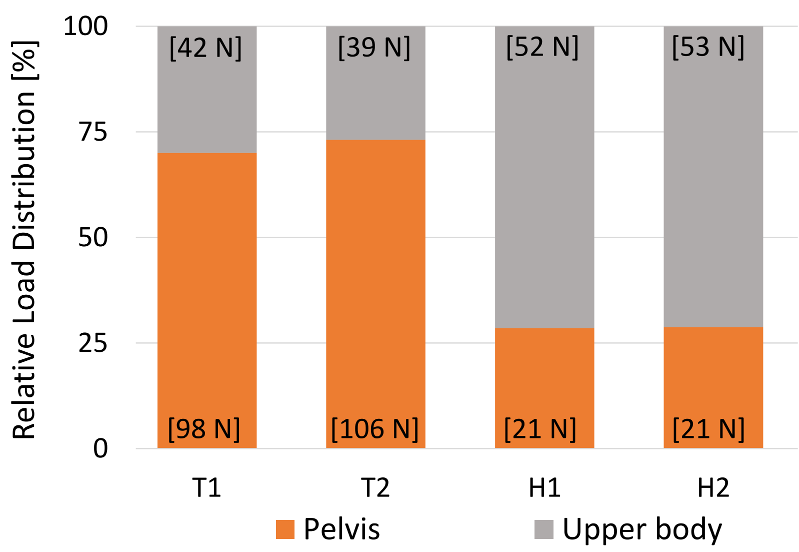


**Fig. 2:** Load distribution between the upper body and pelvis of each backpack (vertical load [N] in brackets).

## Discussion & Conclusion

The results indicate that the **stiffer and longer trekking backpacks** are able to **transfer** the load from the upper body **to the pelvis more sufficient** than hiking backpacks. Similar findings of Reid et al. (2006) confirm the results.

One major influencing factor may be the rigidity of the back. The higher rigidity of the TG caused by the **stiff internal frame** seems to transfer the load more efficient to the pelvis, possibly leading to an **injury decrease** especially in the upper body regions. In contrast to Grawe (2014) and Lafiandra et al. (2004), mass dependency could play a role but cannot be definitely proven.

Hence, to ensure an **optimal load transfer** to the pelvis, a **rigid link** between the shoulder straps and the hip belt and also an **appropriate distance** is recommended. Moreover, the **positioning and the strap force** of the hip belt and also the **attachment** (position, angle) of the shoulder straps on the backpack (Reid et al., 2001) play a role to improve load transfer and comfort (Fig. 3). Consequently, the validated **dummy** can serve as a **reliable tool** for LCS improvements, e.g. in sports industry.

Because of the male anthropometrics of the dummy, a generalizability of the results to a heterogeneous cohort must be performed with care.
Thus, further investigations using instrumented dummies with different anthropometric characteristics, varying inclination angles as well as investigations with different LCS are needed to approve the results on a wider population and task. To complement design recommendations resulting in an improvement of comfort, additional pressure measurements may be beneficial.

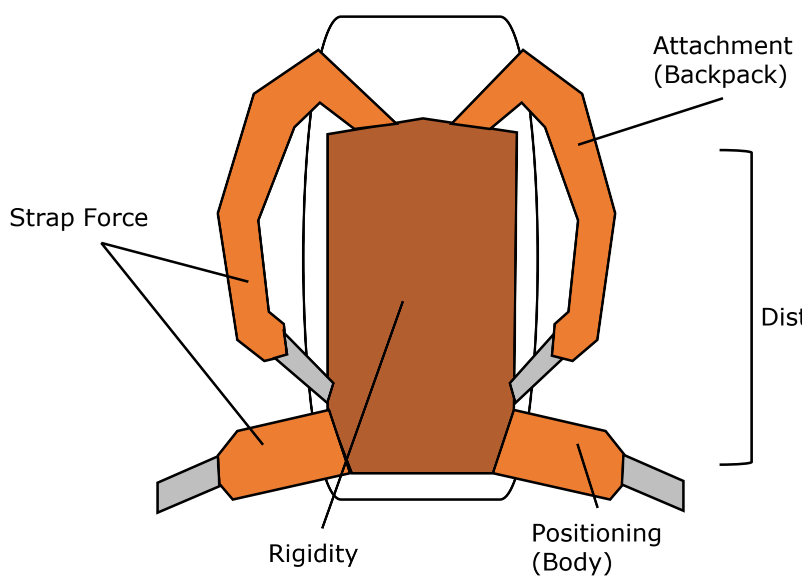


**Fig. 3:** Main factors influencing the load distribution between upper body and pelvis.

### References

Grawe, S. K. (2014). Investigation into Biomechanical Response and Health Consequences of Military Rucksack Design for Female Soldiers. Thesis, The Ohio State University.
Knapik, J. J., Reynolds, K. L., & Harman, E. (2004). Soldier load carriage: historical, physiological, biomechanical, and medical aspects. Military medicine, 169(1), 45-56.
Lafiandra, M., & Harman, E. (2004). The distribution of forces between the upper and lower back during load carriage. Medicine and science in sports and exercise, 36(3), 460-467.
Reid, S. A., Bryant, J. T., Stevenson, J. M., & Doan, J. B. (2001). Biomechanical assessment of rucksack shoulder strap attachment location: effect on load distribution to the torso. RTO Meeting Proceedings 56. Kingston: Queens University.
Reid, S. A., Stevenson, J. M., & Kudryk, I. (2006). Assessment of the effect of No Stay, Bent Stay or Straight Stay when the Clothe the Soldier Rucksack is worn with the Fragmentation Vest (No. DRDC-TORONTO-CR-2006-298). Kingston: Queen´s University.
Wettenschwiler, P. D., Annaheim, S., Lorenzetti S., Ferguson, S. J., Stämpfli, R., Psikuta, A., Rossi, R.M. (2017). Validation of an instrumented dummy to assess mechanical aspects of discomfort during load carriage. PLoS ONE, 12(6),1-15.