Systematic evaluation of human-exosuit physical interfaces

Matthew B. Yandell[1*], Dmitry Popov[2*], Brendan T. Quinlivan[2], Conor Walsh[2†], Kathleen O'Donnell[2], Karl E. Zelik[1†]

[1]Vanderbilt University, [2]Harvard University,
[*]co-first authors, contributed equally, [†]corresponding authors
karl.zelik@vanderbilt.edu, walsh@seas.harvard.edu

Summary

Exoskeletons are being developed at a growing rate, with capabilities that restore healthy function, augment performance beyond natural biological limits, and take advantage of passive dynamics. However, an often overlooked aspect of exoskeleton design is the physical interface with the human body, which can limit performance benefits. It has been observed that as much as 50% of the mechanical power generated by exoskeletons can be lost in transmission to the body (Cherry et al., 2015). There is a critical gap in understanding how to couple exoskeletons to human users to effectively augment movement. This is problematic for both traditional rigid exoskeletons and for soft exosuits. Although the difficulties of attaching to the body are well-known, only a few studies have published data characterizing interface dynamics (Asbeck et al., 2015; De Rossi et al., 2010; Quinlivan et al., 2015). The long-term goal of this research is to understand how to create safe, comfortable and secure device attachments to the human body, which improve mechanical power transfer and reduce interface migration (slippage). Here we present initial efforts to characterize the performance of various human-exosuit physical interfaces, with an emphasis on identifying key outcome measures.

Introduction

Power transmission issues related to the human-exoskeleton interface are problematic for both rigid exoskeletons and soft exosuits. In traditional rigid exoskeletons, actuation forces are often applied normal to human body segments and energy can be lost to compression of soft tissues. Securely coupling to human body segments can be difficult, particularly when exoskeleton forces are applied in shear as in the case of soft exosuits (Fig. 1). In addition to compressing soft tissues, exosuits also lose energy through deformation of the textile interface and skin/tissue stretch. A critical challenge is to improve the transmission of power (via forces) to the body to effectively augment human capabilities. This power transmission issue is relevant not only to exoskeletons and exosuits, but also to other assistive devices such as prostheses (Zelik et al., 2011).

Apart from power transmission, another factor affecting exosuits and exoskeletons is migration (motion/slippage of the interface relative to the skin) over time. This can affect how applied assistance is transmitted into joint torques, or in the worst case can result in the device not functioning at all. One way to limit device migration is by anchoring against bony prominences; however, such locations are not available on certain parts of the body. Alternatively it is possible to anchor only to conical limb segments (e.g. shank or thigh) using conformal interfaces that apply compression to soft tissue (Ding et al., 2016).

Here we present initial efforts to characterize the performance of various human-exosuit physical interfaces, with an emphasis on identifying key outcome measures. This research is essential to providing quantitative feedback to guide the design of exosuit interfaces that safely, comfortably and securely attach to individual body segments. Innovations in how we physically couple to the body have the potential for broad applications, and could enable transformative advances in human augmentation technology.

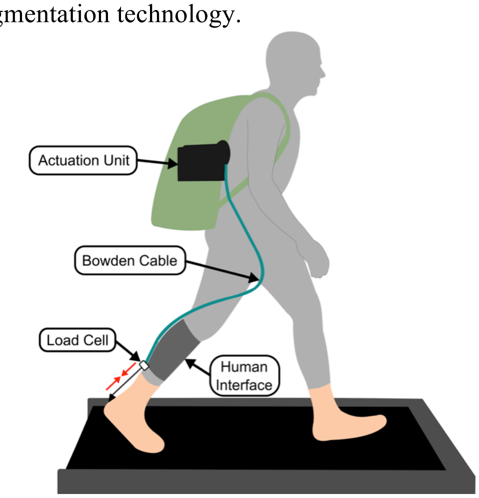

Figure 1. Test setup for treadmill walking trials where a mobile actuation unit mounted on a backpack generated force and Bowden cables were used to transmit that force to the shank interface.

Methods

We explored a variety of attachment methods, different liners for gripping to the skin, different amounts of body coverage and different amounts of mechanical compression provided by the interface. We performed both static (standing posture) and dynamic (walking) tests while measuring the displacement of each interface relative to the human body. Loading >500 N and >2000 N/s was applied in both static and dynamic cases using a mobile actuation system (similar to Asbeck et al., 2015). Bowden cables were used to transmit the forces from the actuation system to the interface under testing (Fig. 1). On the actuator side, the Bowden cable sheath connects to the outer frame of the pulley cover and its inner cable attaches to the pulley. On the human side, the Bowden cable sheath connects to the back of the human interface component on the shank, while its inner cable extends further to the metal bracket at the back of the heel. As the motor rotates, the distance between the two points is shortened, generating torque about the ankle joint.

We identified four key outcome measures for evaluating human-exosuit interfaces: (1) interface migration (slippage) over time relative to the skin, (2) interface force-displacement characteristics during dynamic loading, which encompass stiffness properties and energy loss due to both device and soft tissue deformation, (3) compression and shear pressures provided by the interface, and (4) subjective user comfort. As an example of the proposed characterization, we quantified performance of several exosuit interfaces.

Results & Discussion

Preliminary results showing interface migration over time due to repetitive loading and displacement during dynamic loading are depicted in Fig. 2. We have also begun to characterize interface force-displacement relationships (not depicted). Additional data analysis and experiments are ongoing to evaluate other key outcome measures, in anticipation of more comprehensive systematic studies.

Acknowledgements

This research is supported by the Defense Advanced Research Projects Agency (DARPA), Warrior Web Program (W911NF-14-C-0051), the National Science Foundation (CNS-1446464 and DGE1144152) and the National Institutes of Health (K12HD073945). This work was also partially funded by the Wyss Institute, the John A. Paulson School of Engineering and Applied Sciences at Harvard University and the Vanderbilt University School of Engineering.

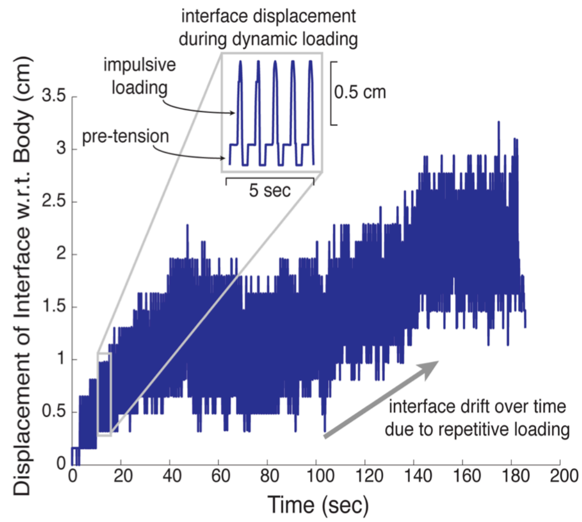

Figure 2. Interface displacement with respect to the body vs. time, as a result of repetitive impulsive loading. Interface migration (slippage) is evidenced by the shifting of the baseline displacement on a longer time scale. Inset: displacement during dynamic loading is seen on a shorter time scale, where the interface displaces temporarily and then recoils back to the same position.

References

Asbeck, A. T., Rossi, S. M. M. D., Holt, K. G. and Walsh, C. J. (2015). A biologically inspired soft exosuit for walking assistance. *Int. J. Robot. Res*.

Cherry, M., Kota, S., Young, A. and Ferris, D. (2015). Running With an Elastic Lower Limb Exoskeleton. *J. Appl. Biomech.*

De Rossi, S. M. M., Vitiello, N., Lenzi, T., Ronsse, R., Koopman, B., Persichetti, A., Vecchi, F., Ijspeert, A. J., Van der Kooij, H. and Carrozza, M. C. (2010). Sensing Pressure Distribution on a Lower-Limb Exoskeleton Physical Human-Machine Interface. *Sensors* 11, 207–227.

Ding, Y., Galiana, I., Siviy, C., Panizzolo, F. and Walsh, C. (2016). IMU-based Iterative Control for Hip Extension Assistance with a Soft Exosuit. *IEEE Int Conf Robot Autom*.

Quinlivan, B., Asbeck, A., Wagner, D., Ranzani, T., Russo, S. and Walsh, C. (2015). Force Transfer Characterization of a Soft Exosuit for Gait Assistance. *ASME IDETC/CIE*. V05AT08A049.

Zelik, K. E., Collins, S. H., Adamczyk, P. G., Segal, A. D., Klute, G. K., Morgenroth, D. C., Hahn, M. E., Orendurff, M. S., Czerniecki, J. M. and Kuo, A. D. (2011). Systematic Variation of Prosthetic Foot Spring Affects Center-of-Mass Mechanics and Metabolic Cost During Walking. *IEEE Trans. Neural Syst. Rehabil. Eng.* 19, 411–419.