Design of the Orthotic Load Assistance Device (OLAD)

Kevin W. Hollander, Preston Clouse, Nathan Cahill, Alexander Boehler, Thomas G. Sugar
SpringActive, Inc., Tempe, Arizona

Adarsh Ayyar
BAE Systems, Inc., Phoenix, Arizona

1 Motivation

A soldier's carried load has been steadily increasing over the last decades (Knapik 1996; Bachkosky 2007). It is well known that increases in carried load place the soldier at greater risk for musculoskeletal related injuries (Birrell 2007; Orr 2010). In today's military, non-combat related injuries are a major concern as they affect the overall state of health and readiness of the troops (Jones 1996; Cowan 2003). In part, this increase in load is due to the added number and complexity of types of gear expected to be used in theater (night vision goggles, gps units, body armor), but it is also due to the soldier's desire to be prepared for any situation. The recommended maximum load a soldier should carry is 23 kg. In contrast, current individual loads carried range between 45 to 60 kg (Bachkosky 2007).

Devices that aid the soldier with their carried load are required if overall performance is to increase and the likelihood of non-combat related injuries are to decrease. In a joint effort between BAE Systems, Inc. and SpringActive, Inc. a device named OLAD (Orthotic Load Assistance Device) was created to offset soldier carried load, see Figure 1.

2 State of the Art

Investigators have explored the possibility of assisting the soldier with his increase in backpack loads and have had mixed results (Kawamoto 2003; Kazerooni 2005; Walsh 2006). Such devices have been successful in carrying the excess load for the soldier, but have done so at the cost of metabolic efficiency. In terms of metabolic energy, it is far better for the soldier to carry the excess load on his own (Walsh 2006; Gregorczyk 2010). As described by Sawicki and Ferris (Sawicki 2009), to "perturb" someone's gait is done so at the cost of metabolic efficiency.

It is likely that such a perturbation is a result of interference with step to step transition which is reported to be a major determination of metabolic costs (Donelan 2002). Human gait is a fluid transition of weight and energy, both potential and kinetic. To alter this fluidity of motion, ultimately creates inefficiencies in energy transfer and thus increases a person's metabolic cost.

3 OLAD Concept

The SpringActive/BAE design concept is intended; simply, to partially gravity compensate the load from the wearer. Gravity compensation is normally a task for static, stationary mechanisms. However, the SpringActive team has devised a pseudo-gravity compensation mechanism that can dynamically adjust to permit nearly able-bodied gait to occur. A conceptual diagram of the pseudo-gravity compensation mechanism, OLAD can be seen in Figure 2.

Figure 2A shows the basic conceptual mechanism for the OLAD device. The unit attaches at a point on the backpack and at the soldier's feet. The remainder of the mechanism is not connected to the soldier. This approach simplifies the process of donning and doffing the device, as well as permits a single unit to accommodate a wide variety of soldier heights.

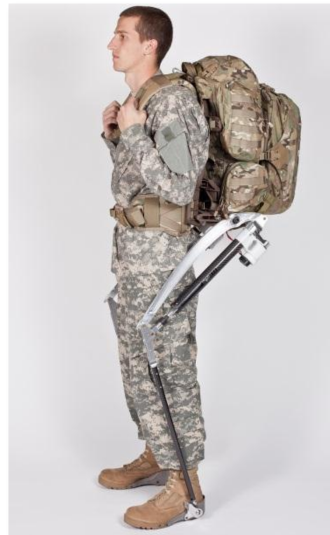

Figure 1: OLAD prototype.

Figure 2B illustrates the effective structure simulated by the Figure 2A mechanism. While the soldier's foot is on the ground, the unit is effectively a passive spring structure, carrying the majority of the backpack load directly to the ground. The points of attachment at the backpack and feet are deliberate to create a comfortable and balanced feel.

Placing an attachment point near the center of gravity (COG) for the backpack, the effective spring mechanism can support the majority of the vertical load imposed. By placing the backpack attachment point slightly behind the COG will cause the backpack to rotate forward, gently pressing into the soldier's back. When properly adjusted, little to no load is felt by the soldier at the backpack shoulder straps.

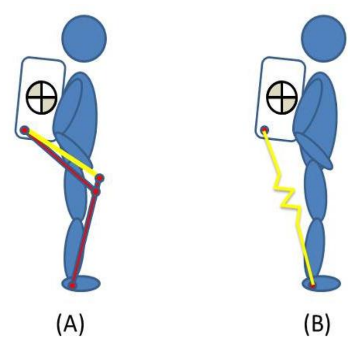

Figure 2: OLAD Concept; a) mechanism configuration, b) mechanism conceptual equivalent.

The key to OLAD's design is that it permits a very natural and unencumbered walking gait to occur, while directing the backpack weight to the ground. While the foot is on the ground the device behaves like a passive spring operating in parallel with the soldier's own leg. However, as the foot lifts into the air for swing, the spring is driven out of the way of the soldier, thus permitting a fluid walking motion to occur.

JackSpring™ Actuator

Due to the varying nature of a soldier's carried load, the stiffness of the actuation system must be adjustable so that the system can remain mechanically tuned. Our previous work in compliant actuation has demonstrated the energy and power benefits of a tuned mechanical system, as well as, greatly simplifying the closed-loop controls (Hollander 2005, Hitt

2009). The OLAD system features the use of the patented JackSpring ™ actuator (Hollander 2005), which allows the system to be optimally tuned for varying loads placed in the pack. This insures maximum energy efficiency from the system while supporting a multitude of backpack weights.

The JackSpring method couples changes in stiffness with actuator displacement. The mathematics describing this approach is discussed in terms of "active" spring coils. Combining the equations of a JackSpring Actuator with those specific to the OLAD mechanism geometry yields a control pattern for able-bodied gait to occur. A representative control pattern for the OLAD device can be seen in Figure 3.

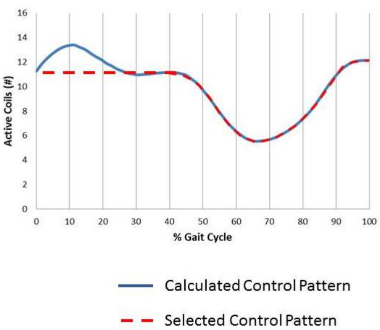

Figure 2: JackSpring™ actuator control pattern.

In contrast to using the calculated control pattern as a basis, a second control pattern was developed. The red dashed line shows the control path used for the OLAD device for walking.

The difference is that the initial active coil count of the spring is held as a constant for nearly half of the walking gait cycle (the majority of the stance phase). This means that for the first half of a step, the motors remain off and only the passive properties of the actuators spring are engaged. It is not until the second half of the step that the actuator motors activate and drive to support the leg movement during the swing phase of gait.

4 Results and Discussion

Two OLAD-style prototypes devices have been constructed. Testing of the OLAD prototype consisted of a single 70 kg subject walking under three conditions: 1) a control, unloaded walking, 2) a loaded walking case (36 kg load) and 3) a OLAD assisted, loaded walking case (36 kg load).

2D motion capture analysis was performed on high speed video captured images of a user walking under the assistance of the OLAD device. Visual markers placed at the foot, ankle, knee and hip were used to determine joint kinematics for the knee and ankle during an entire step. The OLAD device was designed to allow the wearer normal able bodied gait motion while wearing a 36 kg load on their back. The results of the analysis show very good correspondence of the ankle and knee motions to that of able bodies (see Figure 4). It should be noted, that in this design the OLAD exoskeleton structure does not attach to the anatomical limbs of the wearer and thus cannot force the wearer into any particular gait style. Instead, the robot is designed to allow able bodied gait to occur naturally even when carrying a significant load.

A slight hyperextension of the knee was observed during the trial shown in Figure 4 and has been corrected by adding tuned compliance to the OLAD ankle joint.

Recent testing has shown a result of neutral metabolics, when the OLAD device is worn compared to walking loaded and unassisted. However, muscular fatigue and discomfort in the back and shoulders have been greatly reduced.

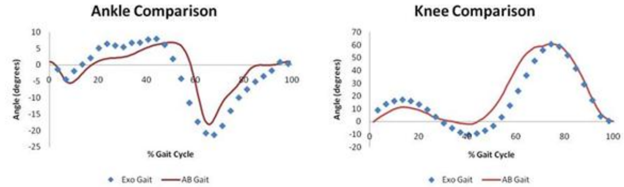

Figure 4: OLAD wearer's joint kinematics compared to able bodied gait.

Additionally, the current device weighs less than 7 kg and consumes between 30 to 40 Watts of electrical power while walking. During standing the power usage is negligible.

5 Conclusion

The information presented here is the result of a preliminary, single subject study. Additional testing and validation will be required before conclusive results can be shared. However, these early results are very exciting and we look forward to sharing our findings once additional data can be gathered. We believe that providing an off loading of weight to the soldier, while maintaining metabolic efficiencies will be beneficial.

6 References

Bachkosky, J., Andrews, M., Douglass, R., Feigley, J., Felton, L. , Fernandez, F. , Fratarangelo, P., Johnson-Winegar, A. , Kohn, R. , Polmar, N. , Rumpf, R. , Sommerer, J. and Williamson, W. (2007). Lightening the Load. Arlington, VA, NAVAL RESEARCH ADVISORY COMMITTEE.

Birrell, S. A., Hooper, R.H. and Haslam, R.A. (2007). "The effect of military load carriage on ground reaction forces." Gait & Posture 26(4): 611-614.

Cowan, D., Jones,BH and Shaffer, RA (2003). Military Preventive Medicine: Mobilization and Deployment. MUSCULOSKELETAL INJURIES IN THE MILITARY TRAINING ENVIRONMENT., US Army, Borden Institute. 1: 195-210.

Donelan, J. M., Kram, R. and Kuo, A.D. (2002). "Mechanical work for step-to-step transitions is a major determinant of the metabolic cost of human walking." Journal of Experimental Biology 205(23).

Gregorczyk, K., Hasselquist, L , Schiffman, JM , Bensel, CK , Obusek, JP and Gutekunst, DJ (2010). "Effects of a lower-body exoskeleton device on metabolic cost and gait biomechanics during load carriage." Ergonomics 53(10): 1263-1275.

Hitt, J., Sugar, T. , Holgate, M. , Bellman, R. and Hollander, K. (2009). "Robotic transtibial prosthesis with biomechanical energy regeneration." Industrial Robot: An International Journal 36(5): 441-447.

Hollander, K., Sugar, TG, and Herring, DE (2005). A Robotic "Jack Spring" for Ankle Gait Assistance. DETC2005-84492, ASME International Design Engineering Technical Conference (IDETC2005), Long Beach, CA, American Society of Mechanical Engineers.

Jones, B., Hansen, B.C. , Kaufman, K. and Brodine, S. (1996). Injuries in the military: a hidden epidemic. Falls Church, VA, Armed Forces Epidemiological Board.

Kawamoto, H., Kanbe, S, and Sanki, Y (2003). Power assist method for HAL-3 estimating operator's intention based on motion information. IEEE International Workshop on Robot and Human Interactive Communication, Millbrae, CA.

Kazerooni, H., Racine, J.L., Huang, L., and Steger, R. (2005). On the control of the Berkeley lower extremity exoskeleton (BLEEX). Robotics and Automation, 2005. ICRA 2005. Proceedings of the 2005 IEEE International Conference on, IEEE.

Knapik, J., Harman, E. and Reynolds, K. (1996). "Load carriage using packs: A review of physiological, biomechanical and medical aspects." Applied ergonomics 27(3): 207-216.

Orr, R. M., Pope, R. , Johnston, V. and Coyle, J. (2010). "Load carriage: Minimizing soldier injuries through physical conditioning-A narrative review." Journal of Military and Veterans' Health 18(3): 31-38.

Sawicki, G. S., and Ferris, D.P. (2009). "Powered ankle exoskeletons reveal the metabolic cost of plantar flexor mechanical work during walking with longer steps at constant step frequency." Journal of Experimental Biology 212(1).

Sawicki, G. S., Lewis, C.L. and Ferris, D.P. (2009). "It pays to have a spring in your step." Exercise and sport sciences reviews 37(3).

Walsh, C. J. (2006). Biomimetic design of an under-actuated leg exoskeleton for load-carrying augmentation. CAMBRIDGE, MA MASSACHUSETTS INST OF TECH. M.S.