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Sensepack: An *In-Between* Wearable for Body-Backpack Communication

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Abstract

Backpacks are often heavy and can be a significant cause of pain. To avoid pain, they must be worn in a certain way and readjusted when they move. Yet, recognising when to adjust a backpack is not self-evident. It is an evolving embodied process—a subtle, negotiation between body and pack. We present *Sensepack*, a wearable that sits *in-between* a backpacker's body and their pack. Sensepack supports novice backpackers to learn to recognise and sense backpack displacement. It monitors shifts in weight distribution, using four textile-sensors to determine imbalances and provides tactile, real-time feedback. We evaluated Sensepack through user testing—indoors on stairs, and in the field. Our preliminary findings suggest that Sensepack may be useful for learning to identify shifts in backpack weight that can cause long-term stress on the body.

Author Keywords

Wearable Technologies, Human Garment Interaction, Hiking, Backpacking, Soft sensors.

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

Introduction

Lower back pain causes more disability than any other condition worldwide. As much as 9.4% of the world population was affected in 2010 [10]. Not only is this of concern with regard quality of life, it also results in high healthcare costs [14]. To investigate how a wearable might make a difference in this space, we chose to focus on hiking. Hiking often involves carrying heavy backpacks over extended periods across varying terrains. Over time, a hiker's pack can easily go out of alignment. According to a prior study, asymmetrical or misaligned backpacks are a significant cause of back pain [6]—an issue for novice hikers who cannot recognise shifts in their pack's alignment. We present Sensepack, a prototype wearable sensor that sits *in-between* the body and the backpack. Sensepack identifies unequally distributed load on the body by measuring pressure at the shoulders and hips. At present it is in the form of a vest. While this is not intended to be the final form, it is an important interim model that provides key positioning support for sensors and actuators, and affords flexible development when working with different backpack models.

Related Works

The relation between backpack use and back pain has been demonstrated with children [9,12]. Load distribution and strapping seem to be key factors for good performance. Lab measurements suggest that high load placement results in significantly higher levels of muscle activity than lower load placement [4], and manipulation of weight, hip-belt use, and shoulder-strap length impact both tension and pressure [11]. Wearables for load monitoring and gait alteration show good results [2], though tests have been limited to a lab environment. Other projects investigate live interactions with fabrics, such as using piezo resistive sensors to create valuable digital output [8] or a wearable for novice snowboarders provides in-the-field feedback on posture, combining pressure and bend sensors with vibration motors [13]. A similar approach is lacking for backpack use.

Methodology

Sensepack was developed using an emergent research-through-design approach cycling through: ideation, prototyping, user testing, data evaluation and reflection. The first two authors have extensive experience backpacking, enabling self-test of functionality before testing on other users. We began with an initial brainstorming session between team members, discussing the impact of hiking gear on the human body during long term hiking. To enrich the discussion, we used tangible objects: backpacks, hiking gear, textiles, and images. Insights were also drawn from personal experiences of bodily expressions during extended backpacking. The collected ideas were gathered in an experience board using materials and photos, as a first move towards material expressions [3]. The main discoveries during these sessions: that backpacks often slide and are displaced due to human motion, and that an asymmetrical distribution of the weight often leads to pain, correlate with [6]. Over the course of the study we developed two prototypes, which we evaluated through walking and hiking. To simulate varying terrains, we conducted two short indoor hikes and one continuous 3-hour outdoor hike. These hikes afforded analysis of pressure shifts on the body. During test runs we conducted open interviews to access in-the-moment impressions of the prototype. All hikes were filmed and the video synchronized with sensor data to identify walking patterns, changes in posture, and unusual events. Qualitative interviews were also conducted, to confirm or challenge assumptions that arose in the unfolding design process.

Figure 1. Rectangle (top) and square (bottom) designs.

Figure 2. Prototype 1 with pressure sensor locations.

From Idea to Prototype

Commercial pressure sensors have hard parts, which may be uncomfortable or provide inaccurate readings due to mechanical distortion when placed between a body and a backpack. We thus created textile-sensors using velostat, a piezoresistive material that affords unobtrusive and conformable design [7]. We developed two prototype soft sensors: (1) a rectangular strip of velostat sandwiched between conductive fabric and (2) a square of velostat with conductive fabric sewn to opposite edges (Figure 1). When measured with a multimeter, both sensors indicated equal response. We opted for the second version, as sewing through the velostat randomly varied resistance, and the second design required less sewing. We tailored a vest shaped garment and incorporated the sensors at the hips and shoulders (Figure 2)—the main contact areas between body and pack. All sensors were connected using conductive thread and brought to the centre pocket on the front side to an Arduino 101. With a 10-bit AD-converter, the default values of our sensors fluctuated between 250 and 300 without load.

Sensing Pressure

Initial self-tests used a 20kg backpack worn over the vest (Figure 3). After strapping and walking on a flat surface, readings levelled out around 470. We verified each sensor by tapping them and conducted a preliminary indoor-hike. Comparing the graphs with video enabled us to determine different walking patterns and certain movements e.g. turning, re-strapping the pack, even individual footsteps. To gain insights into how people with different level of experience approach backpacking, and if and how changes in pressure might indicate displacement of the pack, we conducted two indoor user tests. P1, is an advanced hiker. P2, had never worn a trekking backpack. Participants were briefed to readjust the pack whenever they felt the need and communicate any issue or discomfort regarding the prototype or backpack. The test ended when they removed the pack. Experienced hikers we spoke with claimed an “ideal” weight distribution to be around 80% on the hips and 20% on the shoulders. We were curious to see if our findings might reflect this distribution.

Interpreting Values

We calculated the moving average using 20 successive sensor values to smoothen out curves and identify long term trends. At first, the load on P1 was equally distributed, whereas P2 carried most of the weight on their shoulders (Figure 4). Following a brief tutorial on how to use the pack, P2 redistributed the pressure more evenly and—having done so—claimed the pack was more comfortable. Over ten minutes, the values didn't change significantly—there was a slight increase but not enough to draw further conclusions. The first author then undertook a three-hour outdoor hike, to explore long-term impact of the vest. He was instructed to adjust the backpack as little as possible while hiking so we could see how its displacement might impact pressure. The results demonstrated that the looser the shoulder and hip straps, the more unevenly the pressure was distributed. When the backpack was re-strapped, overall pressure decreased rather than simply redistributing (Figure 5). This outcome may be due to sensor behaviour, wrinkling or uneven pressure. We have, as yet, been unable to determine the cause.

To understand the data, we conducted an open interview session with hiking novices, experts, and a former hiking gear advisor. It seemed that experienced

Figure 3. Sensepack setup with mounted backpack

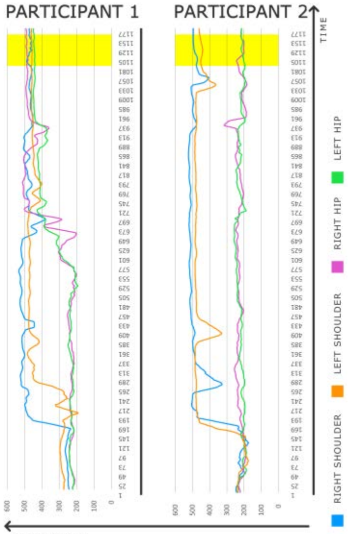

Figure 4. Comparison of weight distribution

hikers develop a sense over time—described by many participants as an instinct—by listening to their bodies. This instinct allows them to adjust their backpack before they experience pain. Critical feedback included the desire to travel light and the urge to be disconnected from technology. Many participants reported struggling with their backpack during initial attempts. One interviewee explained how it took her the first out of six months of a South America trip before she could adjust her backpack comfortably. These insights helped narrow our target group to novices and brought up a new challenge: to develop a tool that can be used to enhance the senses of novice hikers to improve their backpack interaction and speed up their independence from the technology support.

Testing Tactile Feedback

To design a functional feedback system for Sensepack we needed to consider that hiking and the backpack itself already provide feedback. In motion, friction occurs at the contact points between body and pack; the hiker also receives feedback from the terrain. The challenge was to design a user experience that can be distinguished in this dynamic environment and be informative for the wearer. We experimented with sound, vibration and mechanical impact for actuation. Sound commonly works as a notification signal. We needed to explore its usefulness on the body in this context. Vibration provides stimulation that could be mapped to the intensity of pressure change. Mechanical impact provided a curious alternative to sound or vibration, enabling us to disrupt the body and thereby destabilise perception [15]. To understand reactions to these feedback types and identify potential body locations, we conducted an interactive interview session, using props for embodying temporal form [15]. This method uses actuators as a tool for users to explore body areas and personal reaction to stimulation. As props we used (a) four buzzers, (b) four vibration motors and (c) a single stepper motor. In (a) and (b), all actuators ran simultaneously, providing concurrent signals at four different locations. With (c), the tangible feedback was created by attaching four wings to the motor, to twist the user's clothing with increasing pressure as it turned. These props were tested while walking and wearing the backpack. Observations were mapped to the body to afford analyse (Figure 6). We received the most positive feedback for (b)—the vibration approach. All participants said they could relate to the feeling and were courageous in exploring different locations. Different users claimed the body part 'spoke' to them, while they were placing the vibrator below their collar bone. Most participants preferred the feedback close to the contact points of the pack.

Aesthetics

These feedback tests hinted at the complexity of cross-body recognizability [1]. To run the actuators in different configurations and maintain an overview, we created four soft switches out of bright red fabric (Figure 7 and 8). Each switch consists of an arrow shaped sleeve that closes the circuit by connecting two parts of conductive velcro (one on the switch and one on the vest). The base outer layer is made of dark grey textile to provide stark contrast with the red switches and ensure they are highly visible to the wearer. When the circuit is closed (and the actuator enabled) the arrow points to the corresponding pressure sensor (Figure 8). To complete the vest, a zipper is used to tighten it and keep sensors and actuators in place. The advantages of this design are: intuitive interface (one

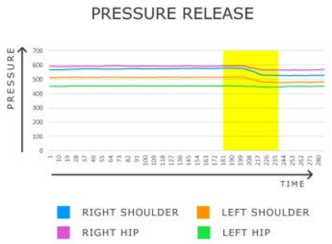

Figure 5. Pressure release after re-strapping

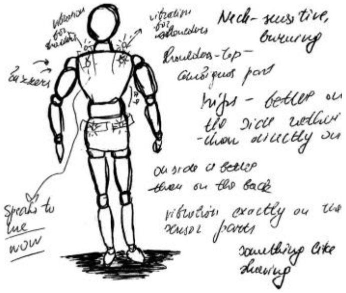

Figure 6. Tactile feedback mapping

actuator = one switch), visual and tangible cues (contrasting colours and pointers), freedom to explore and compare different signals (range of combinations between four switches), and a stable, robust system that sits comfortably on the body. The result is a vest incorporating four pressure sensors—one each on the shoulders and hips—communicating pressure to the wearer through vibration at clearly visible locations that double as switches (Figure 9). These soft switches enable the wearer to activate or deactivate the corresponding actuator, and thus control the system feedback.

Discussion

Carrying a backpack is a common task, which many people can relate to. Soldiers and hikers carry their gear, children often carry heavy school bags, refugees carry their belongings, often for very long distances. But how do each of these people conceive the space between their body and their pack? When designing Sensepack, we focused on creating a wearable that would sit in-between the body and pack to assist a novice backpacker to understand their body posture and pack adjustment needs while hiking. To function, Sensepack requires two factors: the body and the pack. Without both, it loses its meaning. Sensepack thus raises questions around how we understand wearables.

People often wear clothing and use established technologies such as phones, mp3 players and even smart backpacks [5]. Sensepack intervenes in these common practices by locating itself between the body and the accessory. It proposes a new space where the embodiment of wearing takes place, shifting the wearable from being ‘something that is added to the body’ to something that fits *in-between*—to augment the relationship between—the body and the worn. This proposition provides a new perspective on wearables. In use, Sensepack physicalises habits around ‘walking and carrying’ by giving access to information that otherwise would be invisible for a non-expert.

Our research shows that it is an advantage for a backpacker to understand subtle biological signals. Similar to Wearable Automatic Feedback Devices [13], Sensepack assists in communicating physical impact on the body. Contrary to such devices it does not give commands about how the wearer might improve. Nor does it assume the existence of an ‘ideal’ way of carrying a backpack. Rather, it transforms the wearer into their own, personal, self-awareness monitor: able to recognise misaligned loads in real-time through subtle bodily signals and learn from this awareness. Sensepack equally transforms the backpack: from a passive carried object to an active part of the learning process. It does this in real-time by transforming physical pressure into vibration, to communicate pressure distribution of a pack across the wearer’s hips and shoulders. With this information, the wearer can determine whether they need to adjust their strapping and can do so before they experience pain. As part of this process, they can learn to recognise subtle, personal biosignals to achieve independence from the technology.

Conclusion

We presented the design process of Sensepack, demonstrating our findings on pressure distribution while hiking and discussed a new paradigm for considering wearables that sit *in-between* the body and another artefact. Future plans for the project include designing a modular prototype that can be added to

Figure 7. Soft switches

Figure 8. 2nd. Prototype, showing three open and one closed soft switch. The closed switch (under the right hand) points to the hip, where the pressure sensor is positioned.

any backpack, as well as sensors to track posture data, to enrich feedback.

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