Preliminary Study of the Subjective Comfort and Emotional Effects of On-body Compression

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ABSTRACT

The sensation of touch is integral to everyday life. Current haptics research focuses mainly on vibrations, tap, and point pressures, but the sensation of distributed pressures such as compression are often overlooked. We investigated the subjective comfort and emotional effects of applied on-body compression, specifically on the torso and upper arms, through a pilot user study incorporating a novel, low-profile, and actively-controllable compression garment. The active compression garment was embedded with contractile shape memory alloys (SMAs) to create dynamic compression on the body. Qualitative interview data collected (n=8) were used to generate a list of findings to inform the future creation of a computer-mediated compression garment that is wearable, comfortable, and safe for use.

Author Keywords

Wearable Technology; Human-Computer Interaction; Affective Haptics; Human Factors.

ACM Classification Keywords

H.1.2. User/Machine Systems: Human factors; H.5.2. Information Interfaces and Presentation: User Interfaces- *Haptic I/O*

INTRODUCTION

The sense of touch is an important way for us to perceive and represent reality. One of these sensations is counter-pressure, or compression. The feeling of compression is ubiquitous and is used in many applications related to human health, such as graduated stockings to improve circulation, anti-gravity suits of astronauts, and interventions (e.g., weighted vests and massage therapies) to improve emotional well-being [9]. Other applications include haptic communications via compression, which are less attention-demanding, amenable to invoking a wide range of attention capture, and similar to other common human behaviors (e.g., hug) [5]. However, to truly maximize the use of compression in a wide variety of applications, the effects of compression on the human body, especially when used as an interaction modality, must be better understood. Generally, the sensation of compression can be modulated with varying input factors such as application location, intensity, rate, and duration; however, there is a lack of rigorous study with respective to optimal stimulation for a desired experience.

Several studies explored pressure feedback mechanisms using point pressure actuators or wrist-based compression systems [4],[5],[7], [10]. However, not many have examined compressive forces onto larger body areas (e.g., torso) using a garment form factor. Garments are ideal for creating compression due to the large direct-acting surface area, close proximity to the body, and the social ubiquity of clothing provides a physically intimate yet low-profile solution compared to conventional wearable gadgets [8]. Currently, garment-based compression solutions are either (1) non-remotely adjustable garments exerting pressures through stretch or weights (e.g. elastic clothing, weighted vests), or (2) dynamic garments constricting the user (inflatables) [7]. These designs suffer from functional and usability issues, including limitations in portability, bulk, donning/doffing, and mobility. Further, one of the major limitations that prevents rigorous study of these problems is the inability to precisely/ dynamically control the compression generated.

One potential way to address the aforementioned challenges is to develop dynamic compression garments that are simultaneously functional, controllable, and inconspicuous. Recent research in this area has focused on form-fitting garments with integrated active materials, specifically, shape memory alloys (SMA) [6]. SMA wires formed into spring-like actuators (that constrict when heated [3]), have been shown to produce controllable compression (>225mmHg) that scales with applied current [1]. Prior SMA-based active compression garments were small-scale and not user-tested [6]. Therefore, we designed and utilized an SMA-based compression garment to directly study the user experience of on-body compression, driven by the following questions:

RQ1: Is it feasible to use active garment technologies to selectively apply compression on the (upper) body?
RQ2: On what areas of the (upper) body do people prefer/ feel comfortable with applied compression?
RQ3: How do people interpret and respond to dynamic compression as a stimulus?

PASSIVE COMPRESSION GARMENT

A passive garment was used in an internal pilot user study to

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facilitate our understanding of compression garment design, before constructing an active compression garment. The passive garment was made with a non-stretch woven canvas fabric and hook-and-loop straps anchored throughout the garment to adjust pressure on different body locations. Generally, users wanted more compression on the back, lower spine, and flanks, while desiring mobility of the arms and shoulders, as well as flexibility in the front for respiration. Following this feedback, we designed the active garment to include more compliant fabrics, and extended garment length, while placing the actuators away from garment edges (as to not restrict movement), and adding shoulder-free (separate) armbands to allow mobility.

ACTIVE SMA COMPRESSION GARMENT

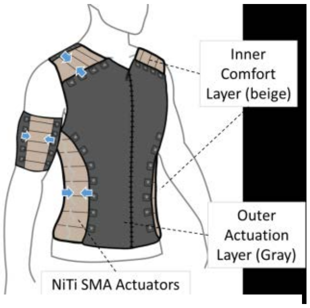

Figure 1. Garment illustration

Our active compression garment system (vest and arm bands) utilizes nickel titanium (NiTi) SMA springs to produce controllable counter-pressures on the body. This active garment (Figure and 2) largely consists of an inner comfort layer and an outer actuation layer, with both layers connected through a front zipper (for ease of donning and doffing). The inner comfort layer is a combination of woven canvas fabric (thick enough to provide structure) on the front, 3D spacer foam mesh on the back (for ventilation and back support), and heat insulation side panels (protecting user from heat generated during SMA actuation) positioned directly below the actuators. Each of these heat insulation panels further consists of three materials: cotton aramid (compliant, comfortable on skin, and flame-retardant), reflective heat shield (sandwiched for heat management), and Teflon^{TM} (low-friction for smooth SMA actuation). The outer actuation layer consists of non-stretch cotton aramid, with SMA spring actuators evenly spaced 1.0–1.5 inches apart, connected to the actuation layer using metal snaps in a parallel circuit configuration. Using 4W–18W of power (depending on the number of actuators in the circuit) the SMA springs actuated on the order of 3–10 seconds. The SMA actuators were formed into 0.048” outer diameter springs with Flexinol® wire (diameter 0.012”, activating temperature 70°C) and heat-treated at 450°C for 10 minutes to set their shape. Seven SMA actuators were used on each side on the torso, five actuators on the armbands, and three actuators on the shoulder regions. Metal snap connectors were used to not only form stable electrical connections, but it also to enable the changing of actuator positions in the shoulder regions. Fiberglass tape was placed down the side seams to mechanically/electrically separate each actuator. The garment was constructed to a standard male size S.

Figure 2. Active garment (from left: front, side, back view)

ACTIVE COMPRESSION STUDY DESIGN

The SMA active garment study used a within-subjects design (n=8, healthy males, age range: 18–27, average age: 23.5). To prevent issues with sizing and fit, only self-identified size S subjects were recruited. During the study, each participant wore a cotton long-sleeve T-shirt to ensure equal baseline conditions. The testing room temperature ranged 19–22°C. Each participant was exposed to 5 conditions: ‘torso’, ‘straight’, ‘diagonal’, ‘mixed’, and ‘shoulder preference + arms’. All shoulder conditions (Figure a–c) included torso actuation. The study was pseudo-randomized; the ‘torso’ condition was performed first because the shoulder test conditions are contingent upon anchoring of the trunk (i.e., without being fitted on the trunk, the garment will ride up as shoulder SMAs are actuated), ‘shoulder preference + arms’ was done last since it uses the most preferred shoulder condition with armbands, and the three shoulder test conditions were randomized.

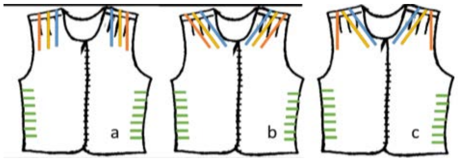

Figure 3. Shoulder test conditions: (a) ‘Straight’ (SMAs oriented vertically), (b) ‘Diagonal’ (SMAs oriented diagonally towards chest), (c) ‘Mixed’ (outer SMAs oriented vertically and inner SMAs oriented diagonally towards chest)

For each test condition, the participants donned the loose-fit, unactuated garment and then the actuators were activated to provide compression for 1.5 minutes. The participants sat with both their hands on the table to provide consistency in postures across test conditions and to prevent their arms from touching the SMA actuators. During each condition, the participants also completed a survey about comfort and distribution of temperature and compression on the body, and they were also prompted to ‘think aloud’ throughout the testing period. Note that the quantitative survey data will not be presented since the small number of subjects did not provide sufficient data to enable a robust statistical analysis. Qualitative interviews were also conducted to understand the experience of wearing the garment, the compression and temperature distribution, emotional changes while compression is applied, interpretations of the compression, and potential improvements to the garment.

RESULTS

Garment Preference and Overall Rating

After all test conditions were completed, the participants were asked to provide explicit test condition preferences and to rate the compression garment on a scale of 1 (extreme dislike) to 10 (extreme liking). 6 out of 8 participants selected the ‘torso + straight shoulders’ as their favorite condition, while remaining participants selected ‘diagonal’ shoulder condition as their favorite. None of the participants preferred the mixed test condition. Through the participants’ think-aloud comments, the reasons for disliking the ‘diagonal’ condition was the feeling of a strong pressure on the collarbones due to the actuators seated on top of the area, as well as the actuators being too close to the neck area and the heat could be felt. The mixed test conditions had the most complaints of feeling too strong of a pressure on their armscye (‘arm holes felt too tight’) as well as being difficult to breathe. As mentioned, the armband preference was split between liking and disliking; some felt it had little value and was restrictive, while others were very satisfied. Overall, the average liking rating for the garment was an 8.4/10.

Qualitative Interview

The following section provides a categorized summary of participant comments and implications for future designs.

Garment comfort. Overall, 6 of 8 participants said that the garment was comfortable. All but one felt that the garment was well-fitted; this participant was of smaller stature and the garment was too long which caused gaping in the shoulders. One participant even commented that the garment felt like a ‘second skin’ and he had not had a compression garment that is so fitted. This outlines the importance of fit since it affects the compression profile of the garment. From the passive garment pilot study, we learned of the importance of allowing mobility and therefore a major design change was the use of more compliant non-stretch fabric. However, we discovered an unexpected advantage with the active garment—SMA actuators. When the SMAs contract, they pull the passive fabric close, functioning like springs. Hence, the garment provides a certain amount of resistance—enough to produce constant compression but still allows expansion with movement. One participant even clearly pointed out that the mobility was much better after actuation. Further, some participants felt that there was a gradual compression starting from the torso to the shoulders. Future iterations will synchronize the rate of actuation on various locations. In terms of pressure distribution, there were a few instances where participants felt that the pressure on one side was stronger than the other. This may be due to a variety of factors including slight differences in power input or actuator lengths. While not all participants noted this uneven loading, future iterations should calibrate the garment actuation such that it provides symmetrical compression and better characterize the absolute pressures applied.

In terms of temperature distribution, some participants reported that the garment started to feel too warm at times, experiencing rapid breathing during such encounters. Work in this area is currently underway to evaluate actuators that have lower activation temperature profiles or materials that provide better thermal insulation. Also, interestingly, half of the participants commented that the lower back felt warm, even though the lumbar area did not have any integrated actuators. This might be due to the back and spine being a high heat and sweat zone [2]. While we anticipated the need for ventilation and used a foam-mesh material for the back, the problem of back heat management remains evident. An implication for future designs include the need for a more thorough consideration of thermal sweat profiles to better modulate the thermal comfort on given body areas. Another comment that warrants future investigation was that it was difficult to dissociate garment compression and warmth. This opens new opportunities to investigate how each of these stimuli contribute to the overall experience of the garment.

Emotional Changes and Comparison to Hugs. The interview also probed the participants’ subjective emotions and how the physical sensation of compression generated by the garment compared to other forms of physical touch (e.g., a hug). Two participants commented that ‘something moving on the body’ as being weird yet fun since it was a new sensation, with a few using the word ‘exciting’ to describe the experience due to the novelty of technology. One participant also demonstrated particular excitement for the condition with the armbands, stating that when the arms were compressed, he felt more active and empowered, ‘like I’m getting ready to exercise’. On the other hand, 5 of 8 participants claimed that wearing the garment felt calming and/or relaxing to them but only when the pressure and temperature distribution were even and consistent. One participant described the sense of calmness descending given the sensation of pressure on the chest especially when taking a breath. Some compared the garment to the sensation of cuddling and that the ‘front felt like a hug but the back like a massage chair’. Another participant compared the garment to a heavy-weighted blanket that he uses; but the garment was said to be less suffocating and much more form fitting (unlike blankets that just provide a sensation on the top). However, 3 of 8 participants pointed out that, while the physical sensation of the garment might be similar to a hug, it is missing the emotional component of real hugs (e.g., joy, love) and therefore feels artificial. The participants were also asked about their subjective feelings after garment removal. While 2 participants did not report any changes, others reported lingering warmth and compression. 4 out of 8 of the participants commented on wanting the garment back on immediately after removal without an explicit question asked. All these subjective emotional effects warrant future studies to clearly understand the positive/negative sensations associated with applied on-body compression.

Word and scenario association. We were interested both in how people might respond to dynamic compression as a stimulus, and also the ways it might be interpreted. We encouraged free word associations (with no limit on terms they can provide) from participants to describe the feelings when compression was applied to the body as well as potential situations they might expect/envision to use the garment. The most commonly used words (by 6 out of 8 participants) include ‘comforting’, ‘cozy’, ‘calm’, ‘relaxing’, ‘warm’, ‘comfortable’, ‘exciting’. Some other terms also used are ‘active’, ‘normal’, ‘hot’, ‘big hug’. Unfortunately, we were unable to fully capture the interpretation these terms might provide (e.g., 'warm' could refer to temperature or the emotional feeling it induces). In terms of potential situations where one might use the garment, the most common association was athletic applications (5 subjects), followed by calming, de-stressing therapeutic devices (3 subjects), and medical purposes for muscle soreness/pain (2 subjects).

DISCUSSION

This study showed that it was feasible to use integrated SMA to selectively apply compression on the body. Generally, the participants were able to detect the applied compression and distinguish between shoulder compression locations, shown in their distinct preference and comments. The subjects generally welcomed compression on the torso and that the preferences for shoulder regions are dependent on the direction compression is applied. In terms of how people interpreted and responded to the compression stimulus, we found generally positive feedback on comfort and emotional effects. Some common themes involve calming/comforting, and warm, and is suggested to be potentially useful in health contexts (exercise or stress-relief). These preliminary results show that there is potential in the use of distributed compression on large areas of the body as an interaction modality, since it is detectable, welcomed if done correctly, and can be induced within a low-profile garment form factor.

There were several recurring themes that warrant further discussion. The major findings directly pertaining to garment comfort include: (1) the need for mobility (to allow joint movement and breathing) and (2) the need for uniform stimulus distribution (any hotspots are disliked). These two variables are in turn mediated by garment sizing and fit. Given this was a preliminary study, the participant pool was limited to only include size S males. However, since the male and female anatomy differs, a women's garment will be designed to capture the variances in experience and to draw a complete set of design principles. Future work will include not only all genders, but an increased number of participants, such that the findings can be better generalized. Through that, we also hope to better understand the important problem of adapting this garment form factor to diverse body types.

We demonstrated that the variable control of compression is possible and captured initial user reactions to the stimulation to inform future designs. With this, more detailed studies of the user experience can be implemented. For instance, the thresholds of perception, effects of variable magnitude/ timing/location of compression, and emotional effects should be investigated. A few subjects also commented on the duration of wear; although not uncomfortable, the garment would not be worn all day unless given an explicit reason to do so. Hence, work understanding the duration of on-body compression that may be applied while remaining comfortable to the user will be undertaken. With the development of garments for both genders, the investigation will shift towards understanding how compression can be modulated through varying inputs (e.g., intensity, duration, rate of compression) and how the perception might change when in a controlled laboratory setting versus *in the wild*.

The current active garment was manually controlled through direct connection to a power supply to provide compression. However, such a system could be easily computerized, enabling computer-mediated communication which may address cross-cutting questions related to its use in social and affective computing (conveying emotions), persuasive computing (inducing behavioral changes), communication, and tele-rehabilitation (remote compression therapy). To achieve this, the next generation SMA-based garment architecture will be developed with wireless control and on-board power systems to allow varying compression inputs.

Other interesting questions revealed include the challenge of dissociating between temperature and compression during the multimodal experience, as well as the novelty effect of wearing the active garment (i.e., instead of calming the participants, wearing the active garment produced feelings of excitement). All of these involve wide implications in the general field of wearable technology and will be further researched. Finally, the application of stimulus on the body should also consider user autonomy (i.e., when or how the user wants compression). Therefore, a user-friendly interface should be incorporated to allow for actuation control.

CONCLUSION

This project sought to understand the comfort and emotional effects of upper-body compression. The study provided insight into the subjective effects of on-body compression, and the active garment has significant potential to be used as an evaluation tool to further study compression as a haptic modality. Finally, this research has broader impacts to improve current compression treatment paradigms and to generate new knowledge in HCI and haptics research fields.

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