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INVESTIGATION OF SUBJECTIVE USER EXPERIENCES OF APPLIED PASSIVE COMPRESSION ON VARYING UPPER BODY LOCATIONS

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ABSTRACT

Strategically-applied compression on the body has been shown to elicit positive affect by creating feelings of calmness/relaxation. Although compression-based therapies are widely used in Occupational Therapy as a clinical intervention, current compression garment solutions suffer from various functional and usability issues and the spatial distribution between different commercially-available solutions vary widely. Currently, little is known about the specific location(s), intensity, and duration of pressure on the body that should be targeted in order to improve physical or mental well-being. With the hopes of contributing to more empirically-based compression garment designs in the future, this work reports a pilot investigation of the subjective user experiences when compression is applied on varying body locations.

Keywords: Wearable Technology, Compression Garments, Compression Therapy

INTRODUCTION

The common haptic sensations of being held, swaddled, hugged, and squeezed, which are perceived by cutaneous receptors in the human skin, all originate from compressive forces on the body. Artificially applying compression on the body has been shown to decrease anxiety, promote feelings of calmness, encourage circulation, and improve alertness [1]–[3]. Hence, compression-based therapies are commonly used today as an intervention in clinical populations experiencing sensory processing disorder (SPD), attention deficit hyperactive disorder (ADHD), or autism spectrum disorder (ASD) [1], [4]–[6]. Current garment-based solutions are either (1) passive garments that exert pressure when stretched (e.g. elastic clothing, weighted vests) [7]–[9], or (2) dynamic garments that constrict the user with inflated air bladders [10], [11]. In addition, recent developments in developing advanced dynamic garments using active materials (such as shape memory alloys) offer the exciting possibility of designing highly tailored, personalized compression garments in the future [12], [13].

Although compression therapy is widely deployed, the spatial distribution of pressure in current solutions are inconsistent and vary widely. Currently, little is known about the specific location(s), intensity, and duration of pressure on the body that should be targeted to improve physical or mental well-being [10]. Due to the ambiguity and lack of standardized protocols, most compression therapy administrators rely on observation, anecdotal evidence, and personal experience [10], [14]. Therefore, this study takes the first step in understanding users' subjective experiences with applied compression on the upper body. A pilot study was conducted with a passive, adjustable garment to apply compression at different upper body locations. We differentiated subjective experiences of compression on two separate body areas: (1) trunk of body and (2) shoulder areas.

1.1 Test Garment Design

The adjustable test garment (shown in Figure 1) was designed to allow maximal adjustability in the application of passively-applied compression on different regions on the upper body. Hook-and-loop (Velcro®) straps were strategically anchored throughout the garment and were free to move in various orientations. The garment base was constructed using a non-stretch woven canvas fabric to ensure that the compression intensities are relatively constant across participants. The garment was sized to an approximate range of average adult male participants (Size S-M).

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FIGURE 1: PASSIVE ADJUSTABLE COMPRESSION GARMENT (FROM LEFT: FRONT, SIDE, & BACK VIEW)

For compressing the trunk of body, straps were oriented perpendicular to the garment's side seams to provide compression circumferentially on the torso. For compressing the shoulder areas, straps were anchored on the shoulder seams (top of shoulders) and extended vertically, running along either front of the chest or shoulder blades. The strap orientation on the front and back shoulder regions were divided into four separate test conditions: (a) straight, (b) one-side crossed, (c) two-sides crossed, and (d) mixed (Figure 2), as they all provide varying spatial compression profiles.

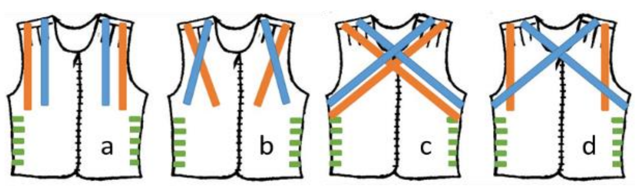

FIGURE 2: SHOULDER TEST CONDITIONS: (A) STRAIGHT, (B) ONE-SIDE CROSSED, (C) TWO-SIDES CROSSED, AND (D) MIXED

In the 'straight' shoulder condition, the straps were oriented vertically downward. In the 'one-side crossed' condition, the two straps on each side of the body crossed each other without crossing over the body's midline. In the 'two-sides crossed' condition, the straps on each side of the body crossed each other across the body's midline. In the 'mixed' condition, the outer strap was vertical and the inner strap was crossed. Markers were placed on the garment to ensure consistency across participants.

One big challenge in the study design was the method for applying uniform compression across subjects of various body shapes and sizes. To our knowledge, no commercially available systems can accurately measure absolute pressures on a contoured, soft tissue system (e.g., human body), especially in a discreet and unobtrusive manner. To overcome this obstacle, participant anthropometrics were measured prior to the study. After donning the passive garment, the straps were adjusted to provide a baseline loose fit (i.e., conforms to the body without exerting pressure points). Any pressure points were corrected by loosening corresponding straps. The straps on the garment were graded with 0.5-inch increments. In each test condition, the straps were tightened by 1.0 inch on both sides from the baseline. This ensures that all participants were given approximately same amounts of compression in each test condition.

1.2 Study Design

A within-subjects design was used in this pilot study with 5 healthy participants (2 males / 3 females; age range: 22-30; mean age: 25.4). Each participant was given a cotton jersey long sleeved T-shirt to wear during the study to ensure the similar baseline compression. Each participant was exposed to 6 test conditions: 'torso', 'straight', 'one-side crossed', 'two-sides crossed', 'mixed', and an informant design. The study was pseudo-randomized; the 'torso' test condition had to be performed first because the shoulder test conditions are contingent upon anchoring of the trunk of body (i.e., without fitting the garment on the trunk, the garment will ride up as the shoulder straps are adjusted). Then the next four trials tested the four aforementioned shoulder conditions in a randomized order. During each of the shoulder test conditions, both front and back straps were adjusted to the same orientation Note that during the presentation of all shoulder test conditions, the torso remained compressed. The final test condition was an informant design exercise whereby the participants sketched out what they wanted or instructed the moderator to move the straps (both orientation and intensity) until it gave the most comfortable and satisfactory compression sensation. This was also an attempt to capture the variability in subjective perceptions in comfort between participants to better inform future designs.

Each of these six test conditions lasted for 2 minutes, during which the participants were exposed to the aforementioned strap orientations in a seated position. A brief survey was completed after each of the test conditions, wherein the perceived subjective comfort level of the garment condition was investigated using the Comfort Affective Labeled Magnitude (CALM) scale, with a ±100 labeled magnitude scale of comfort/discomfort. The scale is said to be sensitive to a wide-range of comfort-related stimuli including garment types with good reliability [15]. The adjectives 'greatest imaginable' defined the fixed end points of positive and negative comfort experience. The CALM scale was used to probe the comfort of specific body locations: trunk of body, middle/lower back, abdomen, front of chest, top of shoulders, upper back/shoulder blade.

To understand the perceived emotions upon compression application in each test condition, the Self-Assessment Manikin (SAM) was used. The SAM is based on the vector model of emotion (valence, arousal, dominance) which has a 9-point scale with human-like figure accompaniment at each point. The valence scale ranges from positive to negative, arousal from excited to calm, and dominance from dominated to dominant [16]. The survey also included questions regarding compression distribution of the garment. The participants were encouraged to 'think aloud' throughout the testing period. Qualitative interviews were also performed to understand the experience of wearing the garment, the compression distribution, emotional changes while compression is applied, interpretations of the applied compression, and potential garment improvements.

1.3 Results and Discussion

1.3.1 Passive Garment Comfort Rating Results

The CALM survey results for each body location are shown (Figure 3). The data was categorized based on survey responses in each location, and each category presents the various test conditions. Collectively, 4 out of 5 participants provided positive ratings on the torso comfort levels (i.e., trunk of body, middle/lower back, and abdomen), while there were more individual differences in the various shoulder conditions. The lack of major differences of comfort on the torso across all test conditions implies that when the shoulder straps are moved, the subjective comfort of the torso is not largely affected. Interestingly, many participants also voiced that the torso compression improved their posture by making them sit upright. In addition, the informant design condition (solid green) unsurprisingly provided the highest median comfort ratings across all body locations, showing that the informant design process was more successful in capturing the participant preferences than the predetermined conditions.

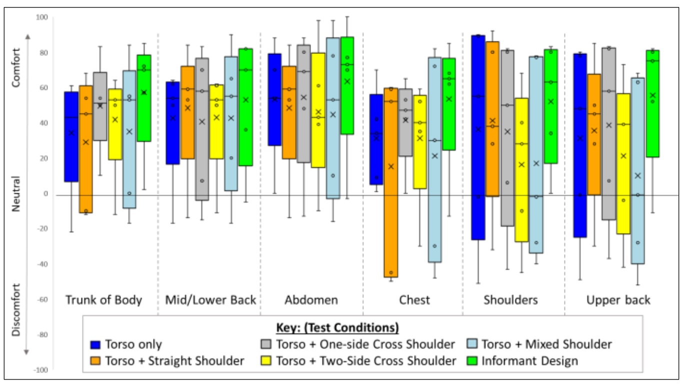

FIGURE 3: CALM COMFORT RATING FOR PASSIVE GARMENT

Participants had lower average comfort ratings on the shoulders and upper back for the 'two-sides crossed' and 'mixed' test conditions. From their 'think-aloud' comments, the participants pointed out that the crossings made them feel like they were strangled. On the other hand, we also had a participant citing the 'straight' condition was uncomfortable because the shoulders were pushed down and was restrictive. Overall, most of the low-ratings were due to discomfort caused by restriction, which made participants feel anxious. Also, one outlier subject categorically did not like any compression on the body; this participant consistently rated the garment as uncomfortable and informed us that on-body compression or hugs are typically unwelcomed.

1.3.2 Passive Garment Emotional Rating Results

Averaged SAM rating results are shown in Figure 4. Generally, the valence measure is more affected by compression (larger distributions across test conditions) than arousal and dominance measures are, with participants feeling generally positive in most test conditions. Along with what we found in the previous CALM comfort survey results, the 'mixed' shoulder test condition performed the worst with more participants reacting to the garment negatively. In the other two measures of arousal and dominance, all the ratings were quite similar across test conditions, with participants trending towards feeling more calm and neutral dominance.

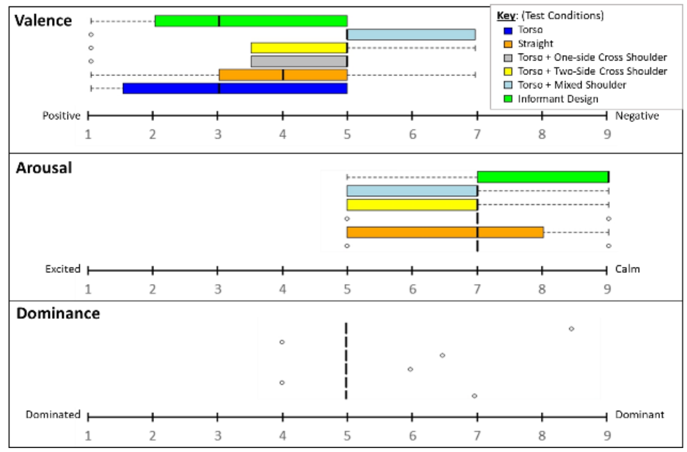

FIGURE 4: SAM RATING RESULTS FOR PASSIVE GARMENT

It is important to note that the participatory design scenario generated ratings that were more positive (mean valence = 3.2), calmer (mean arousal = 7.8), and more dominant (mean dominance = 5.7) than all other designated test conditions. These positive emotions are likely due to the participants' satisfaction with the adjusted garments, their ability to tailor specific stimulation to align with their personal preference, or their satisfaction with the control they have over their garment comfort.

1.3.3 Garment Pressure Distribution and Preference

In terms of garment compression distribution, all shoulder test conditions had 80% (4 of 5) of participants rating the garment as evenly distributed, except the 'two-sides crossed' condition; only 40% (2 of 5) of the participants felt that the 'two-sides crossed' had an even compression distribution. However, the 'two-sides crossed' orientation was still preferred 50% of the time for the front and back sides combined, suggesting that even distribution of compression may not necessarily be preferred by all participants.

TABLE 1: SUMMARY OF PREFERRED STRAP ORIENTATION

Participant ID	Front	Back
S01	Two-side crossed	Straight
S02	Straight	Straight
S03	Two Side Crossed	Two Side Crossed
S04	Straight	Straight
S05	Two Side Crossed	Two side Crossed

As shown in Table 1, the participants preferred either the 'two-side crossed' or the 'straight' test condition. Interestingly, these two pressure distributions were vastly different; 'two-side crossed' was centered on the shoulder straps and 'straight' was centered on the chest area. Hence there may be larger individual differences in terms of perceived comfort than initially expected, and future studies should probe the extent of such variations. A closer look into the data found that the verdict for 'two-sided crossed' test condition was split: 2 out of the 5 participants did not like the pressure distribution at all because it inhibits breathing but 2 out of the 5 participants liked the pressure distribution to be centered on the strap intersection because the resistance was centralized and it 'feels like a hug'; 1 participant was neutral about it. Furthermore, 4 out of 5 participants felt that the pressures could be further tightened once they were satisfied with their preferred shoulder strap orientations.

1.3.4 Participant Comments and Design Implications

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

<u>Garment comfort.</u> Some participants felt that the woven canvas fabric used was too stiff. A clear design implication for this would be that the balance between compliance and stiffness of fabric should be reconsidered. A compliant fabric would provide more comfort to the wearer but will reduce the efficiency of any selected mechanisms in the application of pressure; a stiffer fabric would be more stable and may produce more even compressive forces, but a fabric that is too stiff may not allow complex changes in pressure due to non-conformity with the body. Another comment made by participants is concerns the stark difference in pressure at the edge of the garment (i.e., transition between the pressure-inducing garment and the absence of garment), in which two participants suggested the team to implement a change in future iterations. Hence a future garment design would need to consider a more flexible interface to encourage smoother transition between the presence and absence of pressure. Several participants also requested pressure to be applied not only on the torso but also the arms since 'it would be more similar to a hug'. A female participant also remarked that she could tell the garment was designed for men (and hence was not fitting comfortably), which was contrary to what was expected due to the adjustability of the garment. Therefore, there should be separate designs for men and women to accommodate for varying body shapes and sizes.

<u>Pressure Administration.</u> One of the major themes gathered in pressure administration was the role of movement and breathing while compression is applied. One participant commented that it was 'anxiety-inducing when breathing or movement is restricted, especially when pressures are on the chest and shoulder tops'. Several design strategies can be employed including having less pressure on the outer edge of the shoulders, using a more flexible fabric to allow shoulder joint movement, and reconsidering placement of compressive straps. Several participants thought a tighter fit in the upper back and shoulder regions would be good but increasing pressure directly on the chest should be avoided. Expectedly, a participant also mentioned that while breathing, the pressure distribution felt different as the torso expands. Hence, a more detailed investigation should be conducted to understand the variance of changes in pressure based on torso volumetric changes. One of the most recurring comments, made by 4 out of 5 participants (without explicitly asked), was that the length of the garment should be extended, with pressure applied all the way down to the lower spine. With the right use of fabric interfaces, the problem of 'edge effect' (i.e. poor pressure transition between the garment-generated pressure and the lack of pressure) could also be addressed.

<u>Changes in Emotion and Comparison to Hugs.</u> Three out of five of the participants reported no perceived changes in mood when the garment was worn; the remaining two participants commented that context in which the garment was worn matters. One of the participants said "…towards the end of test, the last condition (participatory design), I felt calmer; but it may be different depending on situations." These results are not unexpected, because prior literature shows that the perceived change in mood is largely dependent on the baseline affect (i.e., if the participant was calm at the start of the test, the change in mood induced by a system will be small and may be imperceptible) and context [17], [18]. Therefore, future investigations of compression on the body should carefully modulate the baseline mood and context by which the stimuli were presented.

Another question presented in the interview was to describe how the physical sensation of compression generated by the garment compares to other forms of physical touch (e.g. a hug from a loved one). One participant commented that the garment was not as good as a hug because of its stiffness. However, another participant said that the pressure distribution was similar to a hug and was particularly excited about the garment since it reminded him of fun memories of his parents' hugs. However, two participants also commented that there were limitations in the garment because it could not replicate the warmth of a hug from a person. Future work should look into the role of temperature in enhancing the subjective comfort of on-body compression garments.

CONCLUSION, LIMITATIONS, AND FUTURE WORK

This study aims to understand the subjective experiences of applied compression through a pilot study that utilizes a passive, adjustable garment to apply compression at different upper body locations. One of the major themes gathered here was the role of movement and breathing while compression is applied. The general consensus seemed to be centered on participants wanting more compression on the back, lower spine, and sides, while maintaining and allowing movement (especially the arms through the shoulder joints), and more flexibility in the front to prevent the inhibition of normal breathing. Otherwise, wearing the strap-adjustable compression garment overall showed favorable subjective/emotional impacts on the participants, with the valence measures trending towards 'positive' and the arousal measures leaning towards 'calm'. The comments and insights obtained in this study will be used to drive the design process in future upper body compression garments.

However, there are limitations to this study, the major one being the immediate generalizability of this study to a specific targeted application. One of the central motivation of this study is to increase our understanding of using strategically-applied compression to improve the overall well-being of users, especially for those of clinical populations experiencing sensory processing difficulties. Therefore, the findings from this study, which uses healthy, young adult populations, may not be immediately generalizable to compression therapy clinical applications. Nevertheless, examining the effects of compression in normative adult samples is an important first step towards understanding the range of physiological and psychological outcome measures for people across a wide range of abilities.

There remain several directions for further investigation regarding the effects of on-body compression. The overarching goal of the project is to gather insights to better inform the design of future compression garments that are ideally customizable to the needs of users. As mentioned previously, regarding the use of compression garment technologies for therapeutic purposes, little is currently known about the specific compression inputs that may improve physical or mental well-being. New garment technologies and designs that are under development will allow for far more sophisticated, tailorable compression garment treatment options. Therefore, this study offers the first step towards that objective as a pilot investigation of the subjective effects of compression on different body locations. Future work should dive deeper into other variables influencing the experience of on-body compression, such as spatial distribution, duration, intensity, and rate of compression. Further, as mentioned, the absolute pressures applied on the body have yet to be measured accurately. In order to truly understand the comfort/discomfort thresholds associated with applied compression on the body, quantitative pressure measurements that can be safely and comfortably applied should also be investigated.

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