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Design of sports compression garments: exploring the relationship between pressure distribution and body dimensions

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Abstract

In recent years, a wealth of research on the functionality of sports compression garments (SCGs) has emerged due to their increased popularity among athletes and SCG brands' claims that they improve exercise performance, shorten recovery and prevent injuries. With most researchers from medical or sports science backgrounds, existing studies are biased towards these fields, neglecting considerations of users and the SCG-body-relationship. To address this gap, this study applied an online survey and wearer trials to create an understanding of user experiences with SCGs.

145 SCG users (65% male, 35% female) completed the online survey. Results show that the respondents have a positive attitude towards SCGs with 78% believing in their recovery-enhancing properties, whilst 49% believe that SCGs improve performance. To examine the behaviour of SCGs on the body, 33 wearer trials with active females (31.0 ± 8.57 years) were conducted. The participants' body measurements were captured using a 3D body scanner (Size Stream, USA). Each participant was fitted into Skins A400 Women's Active Long Tights and Long Sleeve Tops using the brand's size chart. Pressures applied by the garments were measured at 22 locations using a pneumatic pressure measurement device (PicoPress®, Microlab, Italy). The wearer trials revealed that, despite high levels of user satisfaction identified by the online survey, compression levels varied widely across different individuals. This suggests a strong perceptual effect of SCGs. Variations in pressure levels are likely to be associated with variations in fit due to problems with the applied sizing system.

The study adds a more garment- and user-focused outlook to the current research base and highlights the importance of adequate fit of SCGs. For SCGs to provide physiological benefits, they need to apply controlled pressure, which requires pressure prediction during the design phase. This will be addressed by the next stage of this research project.

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1. Introduction

Sports compression garments (SCGs) are skin-tight, elastic garments that are designed to be smaller than the wearer's body to apply pressure to the underlying body (Troynikov et al., 2011). In recent years, a wealth of research on the functionality of SCGs has emerged due to their increased popularity among athletes and SCG brands' claims that they improve exercise performance, shorten recovery and prevent injuries. However, most existing studies do not measure compression and neglect considerations of users and the SCG-body-relationship.

According to Laplace's law, pressure is defined by the relationship between tension and the radius of the object that the tension is applied to (Pressure=Tension/Radius) (Perrey, 2008). This means that the bigger the radius of a limb, the lower is the pressure applied by the same amount of tension. Studies (Brophy-Williams et al., 2015; Hill et al., 2015) indicate that there is a wide range of pressures exerted to different wearers, which is likely to be caused by variations in limb circumferences. Whilst there is currently no 'optimal' pressure level for SCGs (MacRae et al., 2011), it is critical to control pressure levels applied by SCGs in order to give users the opportunity to make informed purchase decisions. To achieve controlled pressure application, the SCG-body-relationship needs to be better understood. This includes understanding the effects of fabric and garment properties, as well as body dimensions and body movement on compression levels (Troynikov et al., 2010; Troynikov et al., 2013). The aim of this study is to create a better understanding of one of the aspects of the SCG-body-relationship by exploring the pressure applied by commercial women's SCGs and linking it to body dimensions and user perceptions.

2. Methods

2.1. Online Survey

An online survey was conducted to explore the under-researched field of users' opinions and attitudes towards SCGs. Questions were developed around three themes: wearer behaviour, product preferences and attitudes. This paper focuses on the attitude part of the survey. An attitude scale based on 5-point Likert scales was developed following a systematic approach: item generation, primary item analysis, and item revision (Riemer & Chelladurai, 1998). The final result was a 12-item attitude scale with a roughly balanced proportion of positive and negative statements that were believed to measure emotional and cognitive aspects of attitudes towards SCGs (Oppenheim, 2000). The randomly ordered items were scored so that a high score reflected a favourable attitude towards SCGs with 60 being the maximum score.

The online survey was conducted using Qualtrics. The survey link was emailed to the secretaries of all registered British Athletics Clubs. The email informed the recipients about the research and asked them to distribute the survey link to their members. The survey link was further circulated in selected online forums. The survey responses were statistically analysed using IBM® SPSS® Statistics (Version 21). Descriptive statistics were used to summarise results and non-parametric tests were applied to compare groups. The reliability of the attitude scale was tested using Cronbach's alpha and mean inter-item correlations with results aimed to be >0.7 (DeVellis, 2012) and 0.2-0.4 (Briggs & Cheek, 1986) respectively.

2.2. Wearer Trials

The objective of the wearer trials (WT) was to analyse the relationship between body dimensions and pressures applied by commercial SCGs. It was further aimed to get wearer feedback via a short questionnaire. 33 females of different sizes, who exercised a minimum of 3 hours per week, participated in the WT. Participants were recruited through posters and flyers distributed across the university campus, in local fitness centres, and in selected online forums. Participation in the study was voluntary and all participants gave written, informed consent.

The WT consisted of three key stages: 1) capturing 3D body scans of participants, 2) collecting perceptual data through a short questionnaire, and 3) quantifying compression using a pressure measurement (PM) device.

Following the first body scan (Size Stream, USA) in underwear, each participant wore Skins A400 Women's Active Long Tights (B33001001) and a Skins A400 Women's Long Sleeve Top (B33001005) in size S, M or L. Sizing was determined by the ratio of height and weight for the tights and the bust circumference for the top using the brand's size chart. 22 locations across the body were marked on the outside of the SCGs using tape. The locations (Fig. 1) were determined based on body and garment landmarks (Table 1). The body scan with SCGs was captured in colour, so that the tape marks would be visible when analysing the data. After the second scan, the wearer feedback questionnaire was conducted.

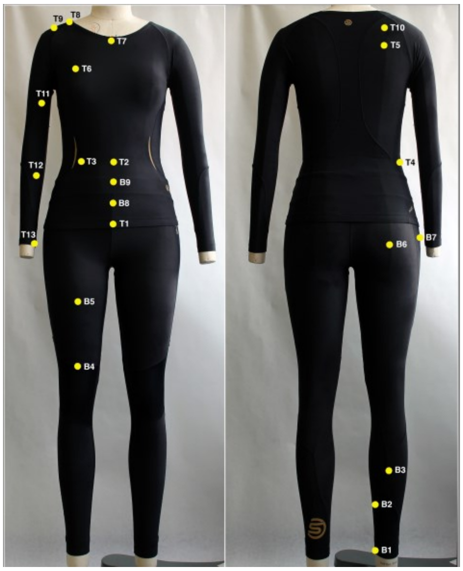

Fig. 1: Pressure measurement locations shown on mannequin

Table 1. Pressure measurement locations of tights and top

Pressure Measurement Location	
Tights	Top
B1: Hem at inside leg	T1: Hem at centre front
B2: 12cm above inner ankle	T2: 5cm above navel
B3: Calf at maximum girth	T3: Front oblique (5cm up from navel, 10cm to side)
B4: 5cm above upper border of patella	T4: Waist at side
B5: Midway along thighbone	T5: Shoulder blade 10cm down from neckline
B6: Gluteus maximus at greatest projection	T6: Front chest muscle at armpit height
B7: 5cm below waistband seam at side	T7: Neckline at centre front
B8: 10cm below navel at centre front	T8: Neckline at top of shoulder
B9: Waistband centre front	T9: Top of shoulder 5cm from neckline
	T10: 5cm down from shoulder at back
	T11: Inner biceps at maximum girth
	T12: Inner forearm at maximum girth
	T13: Sleeve hem at inner wrist

Pressures applied by the SCGs were measured at the marked locations using a pneumatic PM device (PicoPress®, Microlab, Italy). PicoPress® has previously been used for in-vivo measurements of compression and has been found to provide accurate and reliable results (Partsch & Mosti, 2010). PMs were taken with the participants standing in the anatomical zero position with their weight evenly distributed on both feet. The PicoPress® sensor (dia. 50mm) was placed flat between the skin and the SCG centrally under the tape mark on the SCG. The fabric was flat over the sensor with not folds. The PM device displayed values to the nearest 1mmHg. Pressure values were measured twice at each PM location and the mean was used for data analysis.

After the WT, horizontal slices were extracted from participants' scan data at the PM locations using the software Size Stream Studio. Due to non-normality of the pressure data, Spearman's rho correlation coefficient and non-parametric tests were used to statistically analyse the data in IBM® SPSS® Statistics (Version 21).

3. Results

3.1. Online Survey

145 SCG users (64.8% male, 35.2% female; 44.1% ≤40, 55.9% >40 years) completed the survey over a period of one month. The total mean score of the 12-item attitude scale (α = .842; r = .313) was 39.4, i.e. 65.7% of the total maximum score. There was no significant difference in attitude scores between males (*Mdn* = 39) and females (*Mdn* = 40), U = 2244.5, p = .527, r = .05, or age groups (≤40, *Mdn* = 39; >40, *Mdn* = 40), U = 2387.5, p = .415, r = .07.

49.0% of respondents believed that SCGs improve performance, whilst 77.9% believed that SCGs improve recovery. The respondents' expectations were overwhelmingly fulfilled by their SCGs (93.8%). There was a high level of satisfaction among respondents regarding the level of compression and fit of their SCGs with 91.0% and 87.5% respectively stating that they are ‘satisfied’ and ‘very satisfied’ with their current SCGs.

3.2. Wearer Trials

33 females (age: 31.0 ± 8.57 years (mean ± SD)) participated in the WT. They were physically active with an average of 7.0 (± 3.79 (SD)) hours of exercise per week. The participants’ mean key body measurements and size distribution can be found in Table 2. Most participants (75.8%) wore a bigger size in the compression top compared to the compression tights.

Table 2. Mean key body measurements of wearer trial participants in each size category for tights and top

	Tights S (n=22)		Tights M (n=9)		Tights L (n=2)		Top S (n=4)		Top M (n=18)		Top L (n=11)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Height (cm)	166.00	6.63	163.99	7.14	166.30	3.39	160.28	3.56	166.80	7.03	165.17	5.92
Weight (kg)	60.76	3.35	70.12	5.36	80.35	4.45	57.03	3.55	61.74	2.87	71.74	6.83
BMI	22.08	1.87	26.07	1.59	29.00	0.42	22.15	0.76	22.26	2.20	26.28	2.32
Bust circ. (cm)	89.89	3.85	100.32	7.41	101.18	0.90	85.38	1.58	90.42	2.93	101.24	5.73
Waist circ. (cm)	86.44	4.05	93.72	5.26	104.25	1.41	83.28	1.18	87.00	4.12	95.87	6.02
Hip circ. (cm)	100.97	4.38	106.97	3.30	112.17	2.32	101.30	5.18	101.44	4.05	107.04	5.49

Slices were extracted from the body scan files, however, not all tape marks were visible on the colour scans. Nevertheless, it was possible to extract horizontal slices of all participants’ body scans at PM location B6 and of 32 body scans at PM location B3. The mean circumference measurements for each size category are shown in Table 3.

Table 3. Mean circumference of slices at landmarks B3 and B6

	Size	N	Range	Mean	SD
Circumference at B3	S	21	7.07	36.53	2.24
	M	9	4.63	39.71	1.62
	L	2	1.32	40.02	0.93
Circumference at B6	S	22	15.36	98.29	4.25
	M	9	7.72	103.63	2.78
	L	2	3.02	109.58	2.14

The overall mean pressure value measured across all participants was 7.5mmHg for the compression tights and 3.2mmHg for the top. There were high variations in pressure values across different PM locations and across individuals at PM locations B3 (7-23mmHg), B8 (1-16mmHg) and B9 (8-21mmHg) of the compression tights. Pressure levels of the top showed high variations across individuals at PM locations T4 (1.5-11mmHg), T9 (2-10mmHg), T12 (2-11mmHg) and T13 (1-9mmHg).

Fig. 2 and Fig. 3 show the mean pressures applied by the SCGs to the different PM locations on the wearers’ bodies across the range of core sizes S, M and L of the compression tights and top. A Kruskal-Wallis test showed that there was no statistically significant difference ($p > 0.05$) of pressure levels between different size categories of the compression tights at all PM locations. However, pressure values were significantly different ($p < 0.05$) across different size categories of the compression top at PM locations T5, T12 and T13. Follow-up Mann-Whitney tests (with Bonferroni correction resulting in significance level $p < .0167$) showed that pressures varied between sizes S and M and S and L at PM locations T12, $U = 0.5$, $p = .000$, $r = -.65$, and T13, $U = 6.5$, $p = .008$, $r = -.54$.

A Spearman's correlation was run to determine the relationship between the circumference and pressure values at landmarks B3 and B6 in sizes S and M with results shown in Table 4. Size L was omitted due to the small sample size (n = 2).

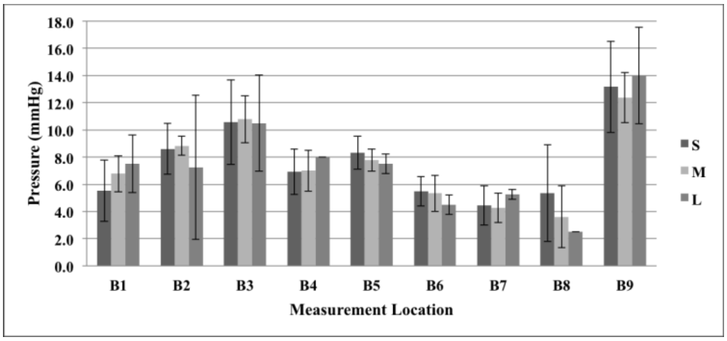

Fig. 2. Mean (± SD) pressure values measured on tights in sizes S, M and L

Table 4. Spearman's correlation for circumference and pressure at landmarks B3 and B6

	Size	N	r_s	p
Correlation: circ. and pressure at B3	S	21	.497	.022
	M	9	5.07	.164
Correlation: circ. and pressure at B6	S	22	.344	.116
	M	9	.829	.006

$p<0.05$, r_s: ±.00-.19 very weak, ±.20-.39 weak, ±.40-.59 moderate, ±.60-.79 strong, ±.80-1.0 very strong

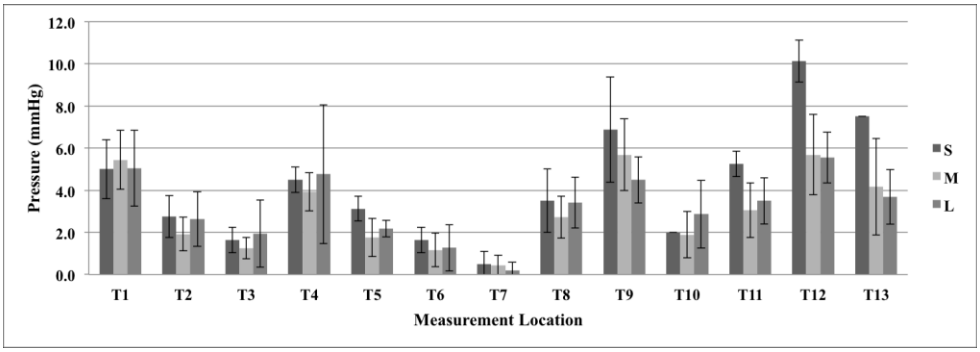

Fig. 3. Mean (± SD) pressure values measured on top in sizes S, M and L

The feedback questionnaire found that 87.9% of the participants rated the level of compression of the tights as 'just right', compared to 66.7% for the top. Most participants stated that they were satisfied with the fit of the compression tights (81.9%) and top (81.8%). 45.5% of participants stated that they believed in the performance-enhancing properties of SCGs with 66.7% believing in the recovery-enhancing properties of SCGs.

4. Discussion

The results of this study indicate a positive tendency towards SCGs among the survey respondents and WT participants, who seem to view SCGs more as a recovery-enhancing than a performance-enhancing modality. There seems to be a high level of satisfaction with commercial SCGs. This includes the perceived level of compression and fit of the garments. However, WT participants were less satisfied with compression levels of the top than the tights. The overall mean pressure level measured at the top was fairly low. Even though an 'optimal' level of pressure for SCGs has not been determined yet, it is unlikely that mean pressure values of 3.2mmHg of the top would have any physiological effects on wearers. As comparison, medical compression levels range from 15 to over 49mmHg (Ramelet, 2002). Variations in pressure at the lower sleeve across different sizes of the top indicate problems with the sizing system, which is based on bust circumference only.

Pressure levels measured at the tights are slightly higher than at the top, however, there are large variations in pressure values across individuals at certain PM locations (e.g. at the calf and waistband). The pressure distribution across the body is not gradual, despite it being marketed as gradual on the Skins website (www.skins.net). Fig. 2 shows that the mean pressure increases from the hem (B1) to the calf (B3) and then drops across the thigh (B4, B5) with low pressure around the hip (B7), but the highest pressure at the waistband (B9). Usually, gradient compression decreases from the ankle upwards to facilitate blood flow towards the heart (Perrey, 2008). The high level of pressure at the waistband caused discomfort for several WT participants and is linked to the fact that the size chart is based on height and weight measurements, leading to a wide range of circumference measurements within one size category. The range of circumference measurements becomes obvious when looking at the slice circumferences

(Table 3). According to Laplace's law, pressure is influenced by the radius of the object receiving tension, thus it is logical that the high range of circumference values measured at the calf (B3) in size S results in a high range of pressures measured (7-23mmHg). However, the correlation between circumference and pressure was moderate positive, indicating that increased calf circumferences result in higher pressure levels. This leads to the assumption that there was a higher increase in fabric tension than calf radii as the fabric was stretched over larger calves.

This study shows that the pressure distribution of the women's SCGs under investigation is not well controlled and that applied pressures are likely too low and not distributed suitably to have physiological effects on wearers. Size designations were not appropriate and resulted in larger sizes in tops than tights for most participants. It was difficult to find participants fitting into tights size L. Sizing caused pressure variations across individuals due to high variations in limb circumferences within each size category of the tights. These findings complement findings from existing studies on men's lower body SCGs (Brophy-Williams et al., 2015; Hill et al., 2015). However, this study adds a user perspective to the research base. Interestingly, SCG users seem to be overwhelmingly satisfied with commercial SCGs, despite the discussed problems. This indicates a strong perceptual effect of SCGs.

5. Conclusions and further study

The WT revealed that, despite high levels of user satisfaction identified by an online survey, compression levels varied widely across PM locations and across different individuals at certain PM locations. This suggests a strong perceptual effect of SCGs. Variations in pressure levels are likely to be associated with variations in fit and fabric tension caused by problems with the applied sizing system.

This study adds a more garment- and user-focused outlook to the current research base and highlights the importance of adequate fit of SCGs. For SCGs to provide physiological benefits, they need improved size charts and application of controlled pressure, which requires pressure prediction during the design phase. This will be addressed by the next stage of this research project.

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