Comparison and Evaluation of Sizing Systems Used in Commercial Women’s Compression Sportswear †

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Abstract: Currently, there is no published research evaluating sizing methodologies for commercial sports compression garments (SCGs), so this study addresses the research gap by analysing sizing systems used for women-specific SCGs. Firstly, fit trials with whole-body SCGs were conducted with 33 active females. Secondly, the upper and lower body size charts of 12 SCG brands were analysed. Thirdly, the fitness of the size charts for the sample was assessed. Findings of the fit trials indicated that the fit of the SCGs varied from the intended fit in most participants at certain body locations, which is problematic for consistent pressure delivery. New sizing approaches are needed for SCGs, as fit requirements differ from conventional clothing, and current approaches appear to be inappropriate. The inclusion of a limb circumference measurement as a key dimension could be beneficial due to the interrelation of fabric tension and limb girth in pressure delivery (Laplace’s Law).

Keywords: compression sportswear; garment fit; sizing; anthropometry; three-dimensional body scanning; Laplace’s Law

1. Introduction

Sports compression garments (SCGs) are designed to improve sports performance, shorten recovery and prevent injuries by applying pressure to the wearer’s body. The effectiveness of SCGs depends on adequate pressure delivery, which is achieved through appropriate garment fit, i.e., a specific relationship between garment and body dimensions, taking fabric properties into consideration [1]. Inappropriate fit of SCGs not only affects pressure delivery, but air gaps between body and garment can also affect thermal comfort and moisture management properties [2]. As SCGs have negative ease, fit requirements diverge substantially from traditional fit principles. Whilst knitted structures extend multi-directionally to conform to the three-dimensional (3D) shape of the human body [3], designing knitted garments with adequate fit and pressure delivery is complex, as garment patterns need to be adjusted based on the fabric’s stress-strain behaviour [4]. Currently, no fit principles for SCGs exist, and fit is not considered by existing research assessing the functionality of SCGs.

Commercial sportswear is generally produced in a range of sizes. Brands develop proprietary sizing systems to fit a specific target population, resulting in fit variations across brands, which can cause consumer dissatisfaction [5]. The process of developing sizing systems involves analysis of the body dimensions of the target population and the correlation of selected key dimensions [6]. Key dimensions determine an individual’s size category, which should offer appropriate fit [7]. Primary and secondary key dimensions for various garment types are defined by British Standards [8]. However, there are no standards for the range of measurements to include. As most sizing systems
only consider one body shape [9], people within the same size category may experience a different fit with the same garment due to intra-individual variations of body proportions.

With currently no published research evaluating sizing methodologies and the key dimensions applied to commercial SCGs, this study set out to analyse sizing systems for women-specific upper and lower body SCGs through (1) practical fit trials, (2) a SCG size chart analysis and (3) an evaluation of the suitability of the reviewed size charts for the fit trial participants’ bodies.

2. Materials and Methods

2.1. Fit Trials

The SCGs used were Skins (Steinhausen, Switzerland) A400 Women’s Active Long Tights (B33001001) and Long Sleeve Tops (B33001005) in sizes S, M and L. Thirty-three active (7.0 ± 3.79 h/week (mean ± SD)) females (age: 31.0 ± 8.57; height: 165.47 ± 6.54 cm; weight: 64.50 ± 7.03 kg; body mass index (BMI): 23.6 ± 2.84 (mean ± SD)) participated in the fit trials. Their body dimensions (Table 1) were captured using a 3D body scanner (Size Stream, Cary, NC, USA). SCG sizes were allocated to participants using the Skins size charts, which were based on chest circumference for the top and a ratio of height and weight for the tights.

| Measurement (cm)       | Mean ±SD |
|------------------------|----------|
| Chest circumference    | 93.42 ± 7.01 |
| Waist circumference    | 89.51 ± 6.54 |
| Hip circumference      | 103.29 ± 5.29 |
| Mid-thigh circumference | 48.17 ± 3.36 |

Photographs of each participant wearing the SCGs were taken (Nikon Coolpix S9400, Tokyo, Japan) from front, back and side views with participants standing straight and arms hanging by their sides. The fit of the garments was analysed using fit guide images available on the Skins’ website [10] as a benchmark for ideal fit and intended seam positioning. The key factor that had to be considered in the fit analysis was that the fabric sat flat against the body without any folds that would obstruct pressure delivery. It was further important to assess seam placement, garment length and the tightness of the waistband. A list of the fit criteria informed by the literature and the specifics of the SCGs under examination was created. Five-point-scales based on Song and Ashdown [11] were selected to score the length and waistband criteria, whilst a three-point-scale based on Lee and Park [12] was used to score the seam positioning and fabric fold criteria. The fit benchmark images and photographs were viewed next to each other on a computer screen one participant at a time, and the fit criteria were scored separately for the compression top and tights.

Kruskal–Wallis tests were conducted to assess differences in fit across sizes, and Spearman correlations (ρ = 0.5–0.69, moderate; ρ = 0.7–0.89, strong; ρ = 0.9–1, very strong) were calculated to identify correlations between body dimensions that could assist size development.

2.2. Size Chart Analysis

Upper and lower body size charts of twelve SCG brands were analysed and compared. All size charts were SCG-specific, i.e., for elastic garments with negative ease, and were publicly available on the brands’ websites. Size charts for compression tops and tights were analysed separately, taking the size chart design, selected key dimensions, and body measurement ranges into consideration.

2.3. Size Chart Fitness for Sample

The analysed size charts, combining circumference measurements with height and/or weight as key dimensions, were assessed for the suitability of combining these dimensions by allocating sizes to the participants using their anthropometric data, which had been collected during the fit trials.
2.4. Limitations

The size charts obtained for the size chart analysis were taken from the brands’ websites without examining the brands’ garments (except for Skins). Since these size charts were published online to guide customers’ size selection, the correctness of the sizing information was assumed. Furthermore, whilst the number of participants was large enough to allow statistical analysis, no deductions can be made for size chart development of a wider population. Future studies developing sizing methodologies for SCGs should include a larger population.

3. Results

3.1. Fit Trials

The size allocation resulted in an uneven size distribution (top \((n = 31)\): 13% S, 58% M, 29% L; tights \((n = 30)\): 63% S, 30% M, 7% L). Two participants were excluded from the analysis of the top and three were excluded from analysis of the tights, as their measurements were outside the size range of S, M and L.

The summarised results of the fit assessment are presented in Table 2. The compression tights were too long for almost half (46.6%) of the participants and too short for 20% of the participants. As a result, the positioning of the knee panel varied slightly across participants and the fit of the compression tights at the ankles was unsatisfactory for a third of participants, as excess fabric created fabric folds at the ankles. For 70.1% of participants, the waistband of the compression tights was too tight, but the fit across the legs and at the crotch was adequate. The length of the compression top was satisfactory for most participants (71%); however, the sleeves were too long for 71% of participants. This caused fit problems at the lower sleeves with unsatisfactory fit for 61.3% of participants. There were no fit problems at the front of the torso; however, for 67.7% of participants the fit at the back was unsatisfactory due to fabric folds. The Kruskal–Wallis tests revealed no differences in overall fit ratings of the compression tights or tops for different garment sizes (tights: \(H(df = 2) = 0.105, p = 0.949\); top: \(H(df = 2) = 3.670, p = 0.160\)).

As the size determination for the compression tights was based on a ratio of height and weight, the limb circumferences of participants within each size category varied substantially (e.g., 15 cm range at mid-thigh in size S of tights). Spearman correlations revealed strong correlations between BMI and waist \((\rho = 0.754)\), hip \((\rho = 0.758)\) or seat \((\rho = 0.778)\) girths and moderate correlations between BMI and mid-thigh \((\rho = 0.503)\) or calf \((\rho = 0.561)\) girths. There were no correlations between BMI and knee \((\rho = 0.440)\) or ankle \((\rho = 0.080)\) girths. The chest circumference was the key dimension for the sizing of the compression top. Spearman correlations indicated a moderate correlation between the chest and biceps girths \((\rho = 0.639)\), but no correlations between chest girth and forearm girth \((\rho = 0.417)\), wrist girth \((\rho = 0.263)\) or arm length \((\rho = -0.035)\) were detected.

| Tights \((n = 30)\) | Median | Mode | Range | Top \((n = 31)\) | Median | Mode | Range |
|-----------------|--------|------|-------|-----------------|--------|------|-------|
| Length          | 3      | 3    | 4     | Length torso    | 3      | 3    | 2     |
| Seam positioning| 2.5    | 2    | 1.5   | Length sleeves  | 5      | 5    | 3     |
| Waistband       | 2      | 2    | 2     | Seam positioning| 3      | 3    | 2     |
| Folds ankles    | 2      | 1    | 2     | Folds torso     | 2      | 2    | 2     |
| Folds shins/calves| 3    | 3    | 1.5   | Folds shoulders | 2.5    | 2.5  | 1     |
| Folds knee      | 2.5    | 3    | 1.5   | Folds underarm  | 2.5    | 2.5  | 1.5   |
| Folds thighs    | 3      | 3    | 0.5   | Folds upper sleeves | 2  | 3    | 2     |
| Folds crotch    | 3      | 3    | 1     | Folds lower sleeves | 1  | 1    | 2     |

Length: 1 = too short, 2 = short, 3 = good fit, 4 = long, 5 = too long; Seam positioning and fabric folds: 1 = unsatisfactory, 2 = normal, 3 = satisfactory; Waistband: 1 = too tight, 2 = tight, 3 = good fit, 4 = loose, 5 = too loose.
3.2. Size Chart Analysis

The twelve SCG brands offered four to six alphanumerical size categories with most brands (n = 8) offering five size categories (XS to XL). The key dimensions used by the brands for the sizing of compression tops and bottoms varied substantially. The sizing systems for compression tights can be divided into four categories based on the varying key dimensions applied: (1) BMI systems (n = 4; Skins, 2XU (Hawthorn, VIC, Australia), Body Science (Burley, QLD, Australia), CW-X (New York, NY, USA), (2) torso girth systems (n = 4; refer to Figure 1), (3) limb girth systems (n = 2; CEP (Bayreuth, Germany), Compressport (Nyon, Switzerland)), and (4) a combination of BMI and torso girth systems (n = 2; refer to Section 3.3). BMI systems vary most notably from conventional sizing systems, as no circumference measurements are considered. As is common in sizing across different brands, the range of key dimensions used to define the different size categories varied between brands (Figure 1). The grade increments applied ranged from 4 to 11 cm in girth measurements (with no increment in two cases for larger sizes). Two brands with their roots in medical compression used thigh girth as the key dimension for lower body SCGs. There were moderate correlations between mid-thigh girth and the following body measurements: hip (ρ = 0.643), seat (ρ = 0.603), knee (ρ = 0.670) and calf (ρ = 0.650) girths.

The size charts for compression tops were mainly based on torso girths (n = 7), as in conventional clothing. Five brands used only chest circumference measurements for determination of sizing. One brand used the same BMI system for tops and bottoms (Body Science), whilst three brands used a combination of torso girth and height and/or weight measurements (IntelliSkin (Newport Beach, CA, USA), Linebreak (Melbourne, VIC, Australia), X-Bionic (Wollerau, Switzerland)).

![Figure 1. Chest, waist and hip circumference measurements (cm) used for women’s sports compression garment (SCG) size charts.](image)

3.3. Size Chart Fitness for Sample

The three size charts combining girth with height and/or weight measurements were used to assign sizes to the participants (N = 33). For the compression tights, only two participants (assigned Linebreak and X-Bionic products), could be allocated sizes when considering all key dimensions. For the compression tops, four, two and no participants (assigned X-Bionic, Linebreak and IntelliSkin products, respectively) could be catered for by the size charts when considering all key dimensions. The size charts assumed a positive linear correlation between height and weight or torso circumference.

4. Discussion

4.1. Evaluation of Sizing Systems

The fit of SCGs is critical to ensure that the desired level of pressure is applied to the underlying body. The different sizing approaches for the Skins compression top and tights led to most
participants (76%) wearing a larger size in the top than the tights. Because of the highly elastic, second-skin nature of compression tights, some SCG brands, including Skins, applied a hosiery sizing approach (BMI systems) [13]. The Skins BMI system for compression tights resulted in fit problems with the length and thus the fit around the ankles, even though height was one of the key dimensions of the size chart. Problems with the tightness of the waistband occurred despite BMI being strongly correlated to torso girths. A wide range of height and weight measurements encompassed in each size category caused these fit issues, which triggered inconsistent pressure delivery across individuals, as reported in previous research by the author [14] and similarly by other researchers [15].

The sleeves of the Skins compression top were too long for many participants, causing fit problems at the lower arms. The use of only one key dimension (chest girth) for the compression top sizing caused this issue, as there were no strong correlations between chest and arm girths or length. Chest circumference is the standard primary dimension for the size determination of knitted tops or undervests for women. Height is defined as a secondary dimension for knitted tops and height and hip girth for undervests [8]. The alternative sizing systems analysed, combining torso girth and height and/or weight measurements, were not suitable for the participants, calling into question the underlying sizing methodologies. The main problem lay in the assumptions that height increases linearly with increasing circumference measurements or weight. Size charts based on linear sizing are commonly not based on the actual body measurement dispersion of the target population [16], which could be the case here.

BMI was not strongly correlated to leg circumferences, indicating that BMI systems are not the most suitable sizing approach for SCGs. Likewise, only including chest circumference as the key dimension for tops is not sufficient for SCG sizing, as fit and pressure at the arms cannot be controlled. Using minimal key dimensions is likely seen as beneficial by brands, as size charts based on one key dimension do not alienate consumers (unlike the size charts analysed in Section 3.3), and size categories can be kept to a minimum. However, these size charts result in inadequate fit for a large proportion of wearers within each size category, which affects pressure delivery.

4.2. Considerations for Size Chart Developments for SCGs

The most suitable sizing approach for SCGs likely differs from conventional sizing methodologies because the key aim of SCGs is to apply uniform pressure to each wearer’s body across the range of sizes. There is a case for using limb circumferences as a key dimension for SCGs because Laplace’s Law defines pressure as the ratio between fabric tension and the radius of the underlying object. However, fit around the torso is also important for optimal comfort and support. No strong correlations between limb and torso girths could be identified in the examined population. A combination of limb and torso girth measurements could be a viable solution for SCGs. This should be further explored with a larger population.

Sizing systems for leggings tend to use hip girth as the primary dimension, with height or inside leg length as secondary dimensions [8]. With garment length being identified as a key fit issue, it would be useful to incorporate different length options (e.g., tall or petite) into the sizing system. Whilst this would increase the number of sizes on offer, which brands try to avoid, fit is paramount for SCGs, and different sizing approaches with more size categories are necessary to improve fit. A sport-specific sizing approach might also be necessary for more elite ranges for certain sports in order to provide adequate fit to varying athletic body shapes.

5. Conclusions

Adequate sizing systems are required to control SCG fit across different bodies in the target population and, through this, ensure consistent pressure application across different sizes. Sizing systems based only on height and weight without considerations of body circumferences are problematic for SCGs, as they can result in a wide range of limb circumferences within each size category. The same is true when only one torso girth dimension is used. Other sizing approaches, combining weight and/or height with girth measurements, were inappropriate, as they were based
on a linear approach. The assumption that conventional garment or hosiery size charts can be applied to SCGs is mistaken. Alternative sizing approaches are needed for SCGs. The inclusion of limb circumferences could be beneficial due to the interrelation of fabric tension and limb girth in pressure delivery (Laplace’s Law). This study represents a starting point for further research to develop suitable sizing systems for SCGs that ensure accurate fit and reliable compression across different individuals and sizes. With each brand having developed its own sizing system, sizing is a competitive domain for clothing brands. SCG brands and future academic research evaluating SCGs need to prioritise garment fit, as this can affect the functionality of SCGs.

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