Digital prototyping for women's compressive top for strength training

Youngsook Kim and Fatma Baytar, Cornell University, USA

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Introduction: Although there are no significant differences in muscle quality and capacity between two genders (Vella & Berrangé, 2008), the female body, particularly the upper part, has less strength by 30-50 percent in comparison to male body. The muscular system in women's upper body is composed of pectorals (chest), trapezius (shoulder), abdominals (abdomen), obliques (lateral waist), rhomboid (upper back), latissimus dorsi (mid to lower back), and biceps and triceps (arms) (Vella & Berrangé, 2008). Some of these muscles work in a combination way to activate its growth through strength training. Basic movements for strength training are push (pressing away from the body), pull (tugging toward the body), hinge (bending from the middle body), squat (flexing at knees), and plank (stabilizing the body core) (Beck, 2014). For example, for pushes, the muscles located in chest, shoulders, and arms (i.e., triceps) move together (Brown, 2007). To improve this collaborative performance in muscles effectively and enhance exercising ability, compression sportswear can apply pressure on the body and activate blood circulation as well as relieve muscle fatigue. This way, it can help the body endure at a higher athletic level for extended periods. However, there is lack of studies, particularly for women, related to developing compression sportswear to enhance exercising performance. Therefore, the purpose of the present study was to evaluate a design ideation of a compressive top for strength training targeting women. For this purpose, we developed a digital prototype to analyze pattern-muscle area match. Digital prototyping has been an effective method in apparel product development to visualize patterns on individual bodies and generate a wide variety of ideas (Liu et al., 2016). Fabric mechanical properties can be entered in a 2D/3D patternmaking software to obtain 3D simulations closer to actual fabric drape on 3D human body models (Ancutiene & Sinkevičiute, 2011). 3D body scan data provides models with realistic body size, shape, and proportion to generate true garment fit, particularly for sportswear (Jeong & Hong, 2015).

Methods: The SizeUSA anthropometric data of 2,985 women aged from 18 to 35 were used in statistical analysis to select the representative body size group. Size distributions using crosstabs between bust circumference and height were analyzed with 5 cm size intervals. Additionally, we developed a Qualtrics survey with twenty-six questions and distributed in MTurk upon receiving an IRB approval. Targeted population was American women aged 18-35 who have exercised for strength training while wearing compression sportswear. The questions included perceived compression levels (1 = fitted without pressure to 5 = very tight) for specific body parts and satisfaction levels (1 = extremely dissatisfied to 7 = extremely satisfied) based on consumers' wear experiences in strength training. A 3D body model that was closer to the average body measurements found in the SizeUSA data was extracted from the CAESAR database and imported into CLO3D as an obj file. Flattening technique was utilized to draw patterns directly on the 3D body.

Four types of fabrics, including one mesh fabric, in fiber compositions 80-82% polyester/nylon and 18-20% spandex were tested to identify mechanical properties in thickness (mm), weight (g), density (g/m2), bending length (mm), and bending rigidity (μN.m), extension (%) at 5/20/100gf/cm, and shear rigidity (N/m), in warp, weft, and bias directions, by using CSIRO FAST. These objective fabric measurements were applied to each pattern piece by converting them into relative values (0-99) of CLO 3D. Water vapor permeability (WVP=24*M / A*t) was conducted for about 20 hours in a conditioned laboratory room based on British Standards Institution (BS 7209:1990). To measure pressure in CLO3D, a stress map representing compression measures (kPa) per fabric's unit area through color codes was investigated through 3D animations of static, push, and pull motions by compatibly utilizing Adobe Mixamo. In order to attain appropriate pressure fit in sportswear, 20 to 30 mmHg is typically used in compression sportswear for endurance workout and post-exercise recovery (Paulson-Ellis, 2016). Accordingly, we created digital compression levels which were classified into five phases (mild = 1.06-1.99kPa, moderate = 2-2.66kPa, firm = 2.67-3.99kPa, extra firm = 4-5.33kPa, prescription levels = 5.34 - 6.66kPa).

Results: Based on the SizeUSA data, bust circumference of 92.5-97.5 cm (18.76%), and the height of 162.5cm-167.5 cm (28.71%) were identified as the highest percentages. Also, the cross-size group commonly belongs to these two size ranges indicated the highest percentage (5.80%), in comparison to the other cross-size groups (0.03%-4.76%). Accordingly, this cross-size group was selected as a representative size group, which belonged to normal BMI and to medium size in industry. A total of 281 survey responses were analyzed statistically. From the survey data, the BMI rate was underweight (27.4%), normal (36.7%), overweight (20.3%), and obese (15.7%). For the specific body locations for intensive pressure, no significant differences were found among BMI groups as $p = .981$, $F = .060$. The majority answered waist (52%) as the most for intensive pressure, abdomen (46%) as the next, bust (42%), shoulder (37%), and back (35%). Round neckline was most preferred as 38.3%. Meanwhile, the compression level only at shoulder indicated a significant difference among the BMI groups ($p = .006$, $F = 4.255$). Especially for the normal BMI group, 25-32% out of 70-74% participants, who evaluated as 5 -7 points in the satisfaction levels at shoulder, bust, abdomen, waist, and back, selected 4 points (fairly tight) as the most in compression level.

To support human anatomy, a total of sixteen pattern panels (e.g., collar bone panel, chest panel, side body panels, front panel, back panels) with diverse fabrics were proposed by isolating each muscle group distinct by pectorals, trapezius, abdominals, obliques, rhomboid, and latissimus dorsi (Hayes & Venkatraman, 2016). Fabric A with the highest elasticity in bending rigidity (0.22-0.23 μN.m) was applied to the seven panels of waist and abdomen that 46-52% participants wanted for intensive pressure. Fabric B, presenting the second highest elasticity as bending rigidity (1.03-2.19 μN.m) was applied in the two panels of the chest and breast which 42% participants wanted for intensive pressure. Fabric C, presenting the lowest elasticity as bending rigidity (2.08-5.14 μN.m) was applied in the five panels of shoulder and back which 35-37% participants wanted for intensive pressure. Lastly, for a smooth evaporation of sweat, Fabric D, which was a mesh fabric, was applied in two side panels, and its WVP was the highest value as 887.59 g/m2/day among the four fabrics. The third highest compression level (4 points: fairly tight) assessed as satisfied by the normal BMI group was transferred into 20-30mmHg (2.67-3.99kPa) which was also the third highest compression level from grade 1 to 2 in the medical area (Donnelly, 2019). This compression level was verified by regulating the shrinkage (%) in pattern from 95% to 100% in the weft direction while measuring compression with static, push, and pull motions in 3D animation. In the end, 100% in the shrink level was relatively verified for proper compression levels, resulting in the strongest pressure (3.5-3.99kPa) at waist and abdomen, the middle pressure (3-3.49kPa) at chest and breast, and the lowest pressure (2.67-2.99kPa) at shoulder and back.

Discussion and Conclusion: In summary, a digital prototype of a compression sportswear for women was designed with sixteen panels by applying different fabrics in elasticity. Through this, proper compression levels were applied according to consumers' preferences from the survey data, which led to the highest compression in waist and abdomen, the average in chest, and the lowest in shoulder and back. This study is meaningful in describing a practical procedure how to apply proper compression levels in 3D digital design by considering consumers' opinions. The future study will be investigation on actual pressure fit of a prototype with human subjects.

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