Optimizing sports bra strap design: The role of stitch pattern and stitch length (SL) on the properties of seamless knitted fabrics

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Background. Seamless knitted garments have been touted as the future of next-to-skin apparel, as they offer improved comfort, elasticity, and breathability, along with advantages over the traditional cut-and-sewn manufacturing method, by reducing raw material waste and time required for assembly operations (Datta & Seal, 2022). Sports bras category has seen an influx of seamless knitted styles with functional improvements, using superfine yarns and stitch-by-stitch design capabilities of the seamless technologies (Lau &Yu, 2016; Gorea et al. 2020). Fabric elasticity, absorbency, and durability are important considerations for sports bra materials, however, restricting breast movement is still a key challenge in sports bra design. Bra straps in particular, have far reaching impacts on breast support (Cha, 2012). Zhang et al. (2021) found that elasticity and friction properties of bra straps, and the length and the width of the fabric strips significantly impacted the breast support. Different knit stitch structures have been reported to have a significant influence on dimensional and physical properties of weft knit fabrics (Assefa & Govindan, 2020).

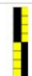
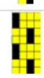
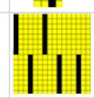
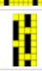
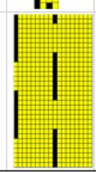
Seamless knitted bras are made on Santoni circular weft knitting machines which are typically 10 – 24 inches in diameter, making tubes of fabric that impart shape to the garment by using individual needle selections, and varying the industrial settings of knit stitch length (SL), elastic yarn tension, and the stitch type (plain jersey, miss or tuck) (Lau & Yu, 2016). The tubular body-size garments have different degrees of extensibility and moisture management in different areas, following a body- mapping design strategy (Wang et al., 2022). Using this technique, the sports bra cups are usually knitted with a higher stitch size than the under-bust band, while the remaining parts, such as back regions and straps, could be knitted with other SL values (Mitchell, 2005). In sports bra product development, multiple trial-and-error samples are created with various stitch sizes, to determine the appropriate fit, pressure on the body, and breast compression level (Gorea et al., 2021). Despite the importance of sports bra straps as detailed above, no studies have been found to investigate the role of SL on fabric properties that influence functionality of bra straps, such as fabric elongation, breathability, and moisture management. The purpose of this study was to determine the role of knit stitch pattern and SL on the elongation and moisture management properties of seamless knitted fabrics for optimization of sports bra strap design.

Method. An industrial 14-inches diameter, 28-gauge, weft knitting Santoni SM8-TOP2 circular machine, with 8 yarn feeders, one of the most advanced circular knitting machines in the industry, with the option to knit, miss or tuck on each of the 1,344 needles, was used (Sterman & Almog, 2022). The yarns were selected from those currently used by the sports bra industry: Repreve® post-consumer recycled Nylon 1/70/68 semi dull natural yarn, plated during knitting with 20– 1/40/13 Nylon cover core spun 210 D bare elastic yarn. Twenty different stitch patterns commonly used for seamless activewear were knitted using machine- settings for SL =70, Repreve® yarn tension = 4gr, and plating yarn tension = 2.5gr. The knitted tubes were allowed to relax for 24 hours at room temperature in the knitting laboratory, then scoured, and low temperature tumble dried according to standard industry practice (Lan &Yu, 2016).

The investigation of the effect of SL and different stitch patterns on fabric properties was conducted in two steps: (1) selection of patterns with low elongation and high air permeability measurements, and (2) development of selected patterns in Step 1 with three different SL values and investigation of their moisture management properties. ASTM and AATCC standard methods were used for all textile testing. One-way ANOVA was used for data collected in Step 1, and two-way ANOVA for data collected in Step 2, via SPSS version 28. For all statistical analyses, $p < 0.05$ was considered significant.

Results and Analysis. Six stitch patterns were selected in Step 1, all having variations of tuck and jersey stitches (Table 1). Based on the analysis of their air permeability and elongation data, patterns #8, #10, #11 and #12 were selected for Step 2, and tubes with SL=70, SL=110, and SL=125 were knitted in these four patterns, relaxed, scoured, and dried. When comparing how different SL values influence fabric properties of the four patterns, the results show gradual increases in fabric density with the increase in SL value for all patterns, and a gradual increase in fabric thickness and weight with the increase in SL value for all patterns except pattern #10. These results suggest that the arrangement of knitted courses when longer tuck stitches are formed, such as in pattern #10, significantly influences fabric thickness and weight properties in an inconsistent manner across the three SL values, when compared with the other patterns. Pattern #10 showed the least difference in air permeability means between all three values of SL. The lack of a consistent pattern in air permeability results between these patterns and SL variations suggests that, when picking the most suitable knit stitch pattern for sports bra straps, multiple fabric properties should be investigated.

Table 1. Knit structure design of the six fabric samples.

Pattern #	CAD stitch design repeat*	Number of tucks in 576 stitches**
1		288
7		288
8		144
10		90
11		216
12		40

**Yellow pixel= jersey stitch, black pixel= tuck stitch*

*** 576 is the smallest repeat that includes all samples*

Elongation data showed a consistent behavior of a gradual increase in stretchability of all patterns across all SL values, but pattern #12 has the greatest increase in elongation coefficient between SL=70 and the other two values for SL. However, the low breaking force shows little variation for pattern #12 between all SL values, suggesting that this stitch structure needs the least force of all patterns to break it, a property not suitable for a bra strap. Moisture management results show that pattern #10 with SL=115 has the best overall moisture management capabilities (OMMC) rating (very good) among all fabrics. There is a wide variance not only between the different patterns, that range from "very poor" to "very good", but also between SL values for a single pattern, such as pattern #11 (from "very poor" for SL=125, to "poor" for SL=115, and to "good" for SL=70). Pattern #8 has consistent poor moisture management properties across all SL values, and pattern #10 has the best OMMC. Patterns #11 and #12 decrease their OMMC with increases in SL values.

Considering all the results presented above, pattern #10 with SL=115 would be the best choice for seamless knitted sports bra straps. This pattern has one of the lowest numbers of tuck stitches, but the tucks have long and spaced-out repeats. This finding is supported by the cross examination of multiple fabric properties, such as fabric density, thickness, weight, air permeability, elongation coefficient, breaking force, and OMMC, for three different SL values.

Significance. The results of this research align with the findings of Kane et al. (2007), highlighting the importance of tuck and jersey stitch combinations on fabric properties, and offer a scientific background for sports bra designers for selecting appropriate knit stitch patterns and SL values. A further study should be conducted by integrating the findings of this research into a sports bra prototype and validate the improved strap functionality, advancing the design of seamless knitted sports bras and improving women's wellbeing and lifestyle.

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