Selected Kirigami Pattern Cutout for Optimal Flexibility and Wicking in Triathlon Performance Wear T-Shirt

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Background and Purpose Triathlon is an endurance sport comprising of swimming, cycling, and running. To ensure performance of the athlete is unhindered, triathlon garments must provide physiological as well as physical comfort. Sweating helps maintain the core body temperature, however, garments act as a barrier between the body and the environment. This results in sweat dripping down rather than creating a cooling effect through evaporation (Guru & Choudhary, 2020). Consequently, triathletes are at risk of heat injuries because of a lack of triathlon garments that help maintain a stable core body temperature (Troynikov & Ashayeri, 2011). Watson et al. (2018) found that thermal comfort of triathlon tops varied based on design, material, and construction of the garment. Furthermore, garments are usually designed for standard body positions, but body dimensions change during active sports (Fu et al., 2011). To provide physical comfort, garments must accommodate the change in body dimensions (Ashdown, 2011). Kirigami cuts induce stretch by the "opening up" of precise geometric cuts. They are expected to improve stretchability of the fabric and increase ventilation in the micro-environment. The use of kirigami cuts in sportswear garments remains unexplored. The present study aimed to develop a prototype of a triathlon top to enhance mobility and thermal comfort by incorporating kirigami slit patterns at locations selected based on skin deformation and sweat distribution patterns.

Skin Deformation and Sweat Dissipation Pattern The sweat distribution pattern on the torso is not uniform; maximum sweat excretion occurs along the dorsal surface, including the lumbar region along the spine and the upper back (Cotter et al., 1995; Havenith et al., 2008). Regarding corporal conformation, maximum change during arm rotation, which replicates the movement during swimming is lengthwise along the obliques and widthwise along the upper back (Chi & Kennon, 2006). During cycling, the shoulder-back region increases significantly in the horizontal direction (Wang et al., 2021). While running, there is a significant increase lengthwise along obliques and widthwise along center back (Kudo et al., 2017).

Method Watkins' design process was used to enable a scientific exploration of the functional design process. As the first step, the problem was accepted, analyzed, and defined through market research and literature review. Next, as seen in Figure 1, five different kirigami patterns were designed based on linear vs non-linear element design, stress distribution at the node, and slits vs holes. The optimal kirigami pattern was selected based on young's modulus obtained from Instron test (ASTM D5034) and water vapor permeability (WVP) obtained from upright wet cup test (BS7209). Last, a prototype was developed by incorporating the optimal kirigami pattern at locations identified as requiring stretch and ventilation.

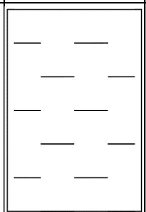
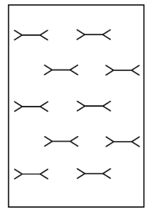
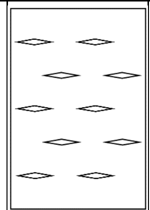
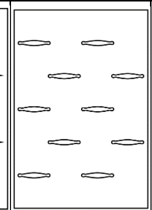
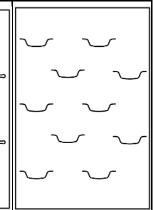
Pattern Name	Control	Line	Chromosome	Diamond	Oblong	Dish
Kirigami Pattern Cutout						
WVP ($g/m^2/day$)	812.58	810.04	799.02	827.83	811.73	832.92
Young's Modulus (Wale)	0.95	0.23	0.21	0.21	0.22	0.20
Young's Modulus (Course)	3.63	1.69	1.08	1.10	0.84	0.16

Table 1. Selected Kirigami Patterns with their WVP and Young's Modulus

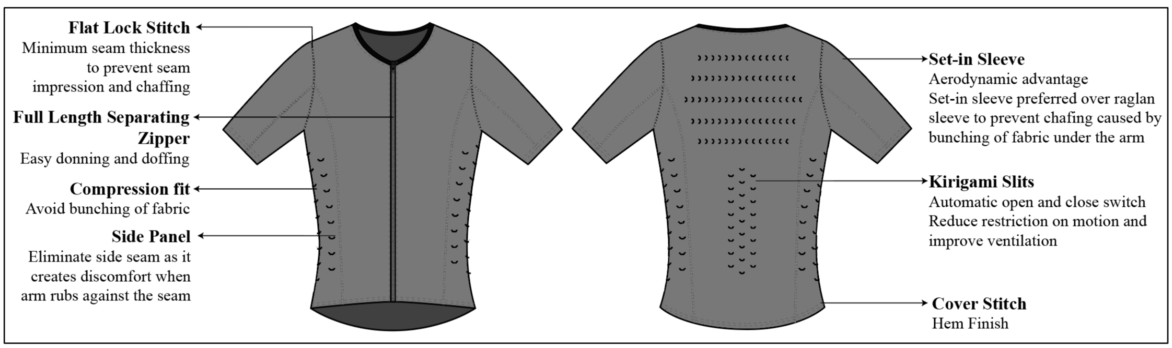


Figure 1. Technical flat and features of the prototype triathlon top

Result Market research showed that issues mainly pertained to tactile discomfort, thermal discomfort, and restriction to motion. Literature review indicated that slits must be placed in a horizontal layout spanning the upper back and in a vertical layout at the lower back along the spine and oblique muscles. The swatches with kirigami patterns had appreciably low young's modulus as the fabric with kirigami cuts expanded through both structural deformation of the kirigami structure, as well as intrinsic deformation of the fabric. Repetitive kirigami cuts manipulate the stress distribution and reduce the load at each cut, thereby, preventing tears at the cut locations. The dish pattern was chosen as it had the lowest young's modulus (0.20 in wale direction and 0.16 in course direction) and highest WVP (832.92 g/m2/day) as seen in Table 1. A prototype was developed with features to improve comfort of the wearer as mentioned in Figure 1.

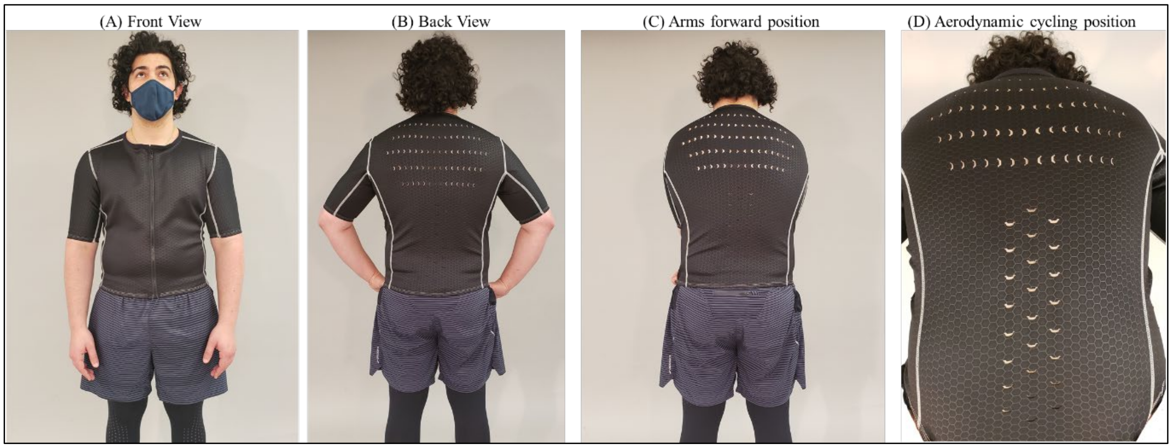


Figure 2: Opening and closing of slits as the wearer moves

Discussion and Conclusion The prototype of triathlon top was developed to prevent sensorial discomfort caused by chaffing due to seams or bunching of fabric, facilitate easy donning and doffing, provide aerodynamic advantage, improve thermal comfort through enhanced ventilation, and enable unrestricted motion. Kirigami slits were incorporated at locations on the back and side panel to enable localized thermal and moisture management. Surprisingly, holes and slits did not improve the WVP as compared to the control fabric as seen in Table 1. Further testing using a sweating thermal manikin is required to understand the advantages provided by the kirigami pattern in terms of thermal and moisture management. Additionally, due to the scale of the study, the pilot test focused on the functional considerations only. Human wear tests should be conducted to provide insight into perception of participants towards the prototype in terms of aesthetic and expressive needs as well. In the current study, design elements were spaced 0.5" apart in the lengthwise and widthwise direction. In the future, difference in young's modulus and WVP with variation in the size of the slit and distance between the slits must be explored.

References

Ashdown, S. P. (2011). *Improving body movement comfort in apparel*. Woodhead Publishing Series in Textiles.

Chi, L., & Kennon, R. (2006). Body scanning of dynamic posture. *International Journal of Clothing Science and Technology*, *18*(3), 166–178. https://doi.org/10.1108/09556220610657934.

Cotter, J. D., Patterson, M. J., Taylor, N. A. S., Cotter, J. D., Patterson, M. J., & Taylor, -N A S. (1995). The topography of eccrine sweating in humans during exercise. In *Eur J Appl Physiol*, 71.

Fu, W. J., Liu, Y., Wei, S. T., & He, J. L. (2011). Research advancements and prospects of compression equipments in sports science. *China Sport Science and Technology*, 47, 114–120.

Guru, R., & Choudhary, A. K. (2020). Study of the Effect Functional Finishes on Thermal Properties Sportswear Knit Garments. *Journal of Textile & Apparel Technology & Management*, 11(4), 1–20.

Havenith, G., Fogarty, A., Bartlett, R., Smith, C. J., & Ventenat, V. (2008). Male and female upper body sweat distribution during running measured with technical absorbents. *European Journal of Applied Physiology*, *104*(2), 245–255. https://doi.org/10.1007/s00421-007-0636-z.

Kudo, S., Fujimoto, M., Isaka, T., & Nagano, A. (2017). Quantitative assessment of trunk deformation during running. *Journal of Biomechanics*, 59, 116-121. doi:10.1016/j.jbiomech.2017.04.019.

Troynikov, O., & Ashayeri, E. (2011). Thermoregulatory evaluation of triathlon suits in regards to their physiological comfort properties. *Procedia Engineering*, *13*, 357-362.

Wang, Y., Li, H., & Li, J. (2021). The skin deformation during cycling on terrains for practical application of compression sportswear. *Journal of the Textile Institute*, *112*(5), 691–699. https://doi.org/10.1080/00405000.2020.1777622.

Watson, C., Nawaz, N., & Troynikov, O. (2018). Evaluation of Triathlon Suit Characteristics Relevant to Thermophysiology of an Athlete. In *Multidisciplinary Digital Publishing Institute Proceedings*, 2(6), 229.