Smart Body – Ergonomic Seamless Sportswear Design and Development

Keywords: seamless / sportswear / knitted

Abstract

Seamfree knitted garment technology is the fastest growing apparel technology in the world. Industry research indicates that Seamfree knitted technology has increased from 1% of worldwide total knitting production in 1977 to 7% in 2003 with further growth expected. Seamfree garments are manufactured with minimal cutting and sewing operations. Currently, products marketed in this product category are mainly produced by a cut stitch shape method that involves knitting tubular fabric blanks without side seams relating to the size and parts of the garment to be made.

Some of the well-known brands such as Falke, Tao, Asics and Odlo utilize this technology in their performance sportswear products. In this paper we will examine the design and development process, principles, parameters and outcomes for engineering ergonomic seamless sportswear utilizing integral seamless Shima Seiki WHOLEGARMENT® knitting technology. This technology allows an integration of the "body zoning" design principles into garment design and style, where various functional materials and structures with specific characteristics are seamlessly incorporated into one garment. The principle of this technology is that these garment parts are knitted simultaneously and as knitting progresses they are merged into one integral seamless garment with differential "zoned" properties. The paper will address the aspects of "body zoning" for active sportswear and performance wear; some aspects of different fibre characteristics and suitability; body mapping and zoning; fabric construction engineering and selection; and styling and garment construction.

Further we will address current limitations of this technology, design and construction constraints and future outlook.

Project Background and Context

Sport is arguably the most dominant cultural influence in the world today. It permeates into almost every aspect of our lives, from fashion and entertainment to business and health.

Our assessment of the global market for sports goods estimated total purchases for sports apparel, footwear and equipment at around €105 billion in 2004. The estimation of sports apparel is approximately €33 billion or 31% of the total market[1,2]

Fashion, styling, technology and performance are now closely linked and this has brought the aesthetics of sport and active wear design in line with the high performance already demanded. It is no longer good enough for active wear clothing just to perform; it must be actually being seen to perform.

This research takes a broader definition approach to performance sportswear - covering Active sportswear and Active Hi-performance sportswear; thereby partly encompassing casual and fashion sports apparel.

Our Ergonomic Performance Seamfree Sportswear design concept primarily targeted elite athlete and sports enthusiasts' apparel markets. We also had a natural extension of these targets into sports apparel with a stylish or fashion component where the Seamfree technology has inherent attributes to create trend leading styles.

Our earlier extensive background analysis of the major sportswear markets indicated that the major influences on consumers in the elite athlete and sports enthusiasts' markets are function; performance and quality, with price a secondary criterion in purchasing decisions. In this research the Seamfree active sportswear design concept was positioned using the major criteria of function; performance and quality with possible dilution of some of these aspects where more fashionability is identified as a main requirement.

Design Key Performance Requirements

The factors that contribute to human performance are many and complex. Research indicates that human performance in both sport and occupational activity is influenced by physical, psychological, technical, and tactical factors. Under each of these broad categories other factors exist (Bookset 2002).

For example, human performance is influenced by physical fitness and body composition, both potentially interacting with clothing and textile properties (among other factors), to determine the performance outcome. For example, as Bookset (2002) points out, in some industrial settings, a heavy protective clothing ensemble may impair performance in someone whose aerobic fitness level is low and the impairment may be exacerbated if that person is small with little muscle mass. Similar examples are evident in sport. A triathlete may improve hydrodynamics and increase swim speed by wearing a buoyant wet-suit, but the wet-suit could impair heat loss and put the triathlete at the risk of heat injury during the subsequent cycle or run leg of the event. Thus, determining the effect of clothing and textiles on human performance is difficult because of this multi-factorial nature of performance; and compounding factors cloud much of the literature.

The main design attributes and requirements as far as sport performance apparel is concerned are:

- Ergonomic requisites
- Design and styling
- Ease and compression
- Thermal balance and thermal regulation
- Layering and apparel essemblies

In some situations clothing and textiles have a more measurable and obvious effect. For example, in specialised sports such as cycling, aerodynamics is a critical performance factor and the clothing ensemble can have a large impact on the maximal velocity. In other situations where exercise must be performed under adverse environmental conditions, use of appropriate clothing is essential for safe, successful human performance.

As number of research reports point out (Shisho (ed) 2005, Bookset 2002) one of the important performance requirements for design of active sportswear is *Ergonomic Requisite*. Ergonomic requirements encompass several identifiable and often interdependent variables:

- product dimensions and their relationship with the wearer/user (sizing and fit);
- shape of the product and shape of the wearer/user ;
- body movement and any changes to this which result from wearing or using the clothing item;
- weight of the garment and/or assembly .

Human performance can most certainly be impaired by apparel with poor fit, restricting factors such as range of motion, reach, and manual dexterity. The ergonomic principles of optimising fit;

reducing weight of the garments or garment assembly; and altering a physical stress of performing a task through innovative garment design remain central to optimising human performance.

Design and Styling, Ease and Compression is another important group of requirements. Ease is defined as the difference in dimensions between the body and the garment (Callan 1998) and may be positive or negative (where dimensions of the garment exceed or are less than those of the body, respectively). What constitutes optimal ease is difficult to define, because properties of the constituent materials; the conditions in which the garments are worn; the function of the garment; and desired styling/design effects all vary.

Appropriate choice of clothing is important in maintaining the body's *Thermal Balance* and *Thermal Regulation* since it provides an interface between the human and the environment for those body parts covered, modifying human thermoregulatory responses.

Fabrics differ in their capacity both to transport moisture away from the skin surface, and to allow perspiration to pass through (vapour permeability). These properties depend on fabric structure and porosity, both of which are influenced by factors such as fibre type, fibre crimp, smoothness, yarn type, and fabric construction. Pascoe et al (1994) state that the closer the fit of the garment, the more important the fibre content is claimed to be, while for looser-fitting garments, fabric construction becomes the more important variable.

Other garment factors which may affect the exchange of heat include the extent and location of closures; yarn construction (e.g. staple, filament); fabric structure (e.g. woven, knitted); finishes (e.g. waterproof, reflective); and the moisture retained in the garment itself.

These factors will also have a large influence on skin temperature. Frank et al (1999) point out that thermo sensors in the skin play an important role in determining an individual's perception of thermal comfort, which may, in turn, affect human performance.

Layering is another important design consideration for active sportswear. Garment assemblies are usually composed of several items that are worn as layers one over another. Individual garments may be constructed from more than one layer of material (such as an outer shell and a lining). Additionally, some materials consist of two or more layers held together in some way:

constructed as a double layer during the material fabrication operation (e.g. integrated double-layered fabrics or as separate layers joined by a separate machining operation or by one of several forms of adhesion or fusing). When layering is used in performance active sportswear, generally there are three distinctive layers in the assembly: next to skin layer, often referred to as "second skin"; mid layer; outer shell. These layers can be constructed from different fabrics, sometimes different fibres or fibre blends and could have different treatments and weights to fulfill separate requirements.

A layering system offers flexibility of the garment assembly as layers could be worn in different combinations to suit the weather/sport conditions. Normally the skin layer will be made out of lightweight, elastic fabric with high moisture/vapour management properties that can effectively transport sweat from the skin.

Melbatex Pty. Ltd. (Australia) offers the following classification for their Next Generation Merino Performance Fabric Layering System collection:

- First layer (Everyday and heavy Duty)
- Middle Layer (Everyday and Heavy Duty)
- Outer Shell (heavy Duty)

Polartec® (USA) offers 3 main groups for their fabrics:

- Next-to-skin fabrics (Power Dry®, Power Stretch®)
- Insulation Fabrics (Classic, Thermal Pro®)
- Weather protection fabrics (Wind Pro®, Wndblock®, Wndblock-Act®, Power Shield®, Aqua Shell®)

Marmot® (USA) also offers 3 main groups of garments for layering that are divided into subgroups:

- Infinity Baselayer
- Thermal Layer
- Barrier layer

Patagonia® (USA) has the following 3 groups:

- Minimalist Base Layer and Lightweight base layer
- Midweight Insulation and Thermal Insulation
- Windproof Insulation

The following characteristics are critical for these layers in layering systems:

1. Next to skin layer (base layer):
    - Keeps skin dry
    - Breathable
    - Dries quickly
    - Has thermoregulation properties (warm when cold and cool when hot)
    - Comfortable on skin
    - Machine washable
    - Stretchable (4-way preferred)
    - Low pilling
    - Versatile in use
    - Possible odour-controlling and anti-microbial properties
    - Can be used as thermal underwear for cold-weather sports or as stand alone for light weather changes
2. Intermediate layer:
    - Warm without weight
    - Breathable
    - Dries quickly
    - Low pilling
    - Machine washable
    - Versatile in use
    - Design/surface interest.
    - Can be used as high-insulation middle layer for extreme cold conditions or as a stand alone insulation layer for mild to cold conditions
3. Weather barrier layer
    - Wind resistant
    - Breathable
    - Warm without weight

- Water repellent
- Durable
- Offers non-restrictive fit
- Abrasion resistant
- Machine washable
- Used as barrier outer in extreme weather conditions

Thus, it doesn't matter how efficient each layer is, it will only work properly as part of a multi-layer clothing system with other layers apparel made of materials that are combined to create what is effectively a comfortable microclimate around the wearer.

Methodology and Methods

Human comfort is influenced by thermal sensations arising from the interaction of the skin with the surrounding environment. People perceive a continuum of cold sensations from indifferent to cool to cold. Hyun (1996) in his studies indicates that human thermal sensitivity varies widely at the surface of the body, while other researchers (Havenith, 2001 and Huizenga et al, 2001) describe the distribution of cold and warm spots in human skin, which are considered to be the reason that different parts of the body respond differently to cold.

Background research shows that clothing has a major effect on modulating the relationship between a cooler environment and the perceived coolness of the wearer[3,4]. For protection against cold conditions, thermal insulation values may not be equally effective in different areas of the body. Since the weight of the clothing can be detrimental to extended wear, cold protective clothing should be designed to maximize thermal insulation material for those body sections that are more sensitive to cold, while leaving other parts of the body less covered to minimize clothing weight and bulk. Thus, cold weather clothing should be designed to provide insulation for the most cold- sensitive sections of the body. This strategic distribution of thermal insulation on the body will benefit the wearer.

A study by Wang et al (2005) simulated real wear conditions and investigated the combined effects of clothing and the environment on human physiological and psychological responses.

This study was used as an initial basis for current research with further investigation into thermal comfort of active sportswear.

This research also involved interviewing 12 subjects: 8 males and 4 females. Subjects were selected to achieve an appropriate cross section of fitness levels, ranging from elite fitness to poor fitness. Subjects were interviewed to find out their perceptions and understanding of the locations of body zones sensitive to cold, heat and moisture build up during exercise. During the interview the subjects were asked to map these sites on the visual presentation of the body (see Figure 1,2,3,4). The data was analysed, synthesised, combined with earlier research (see Wang et al (2005)) and mapped for visual presentation as the basis for garments engineering.

The results showed that for cold or hot environment conditions fabric densities; porosity; moisture management; and thermal properties will need to be zoned within the garments to assist in more efficient thermoregulation of the wearer's body temperature of the wearer.

The body images below demonstrate the body zone sensitivities from high sensitivity to low sensitivity. In this research we focused on design and engineering of active sportswear for cold conditions.

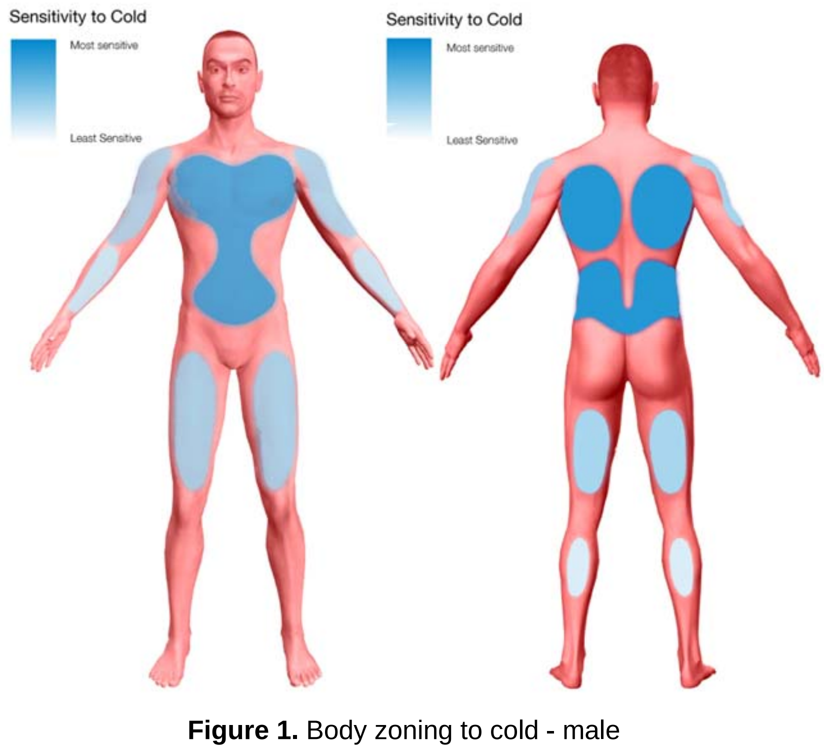

Figure 1. Body zoning to cold - male

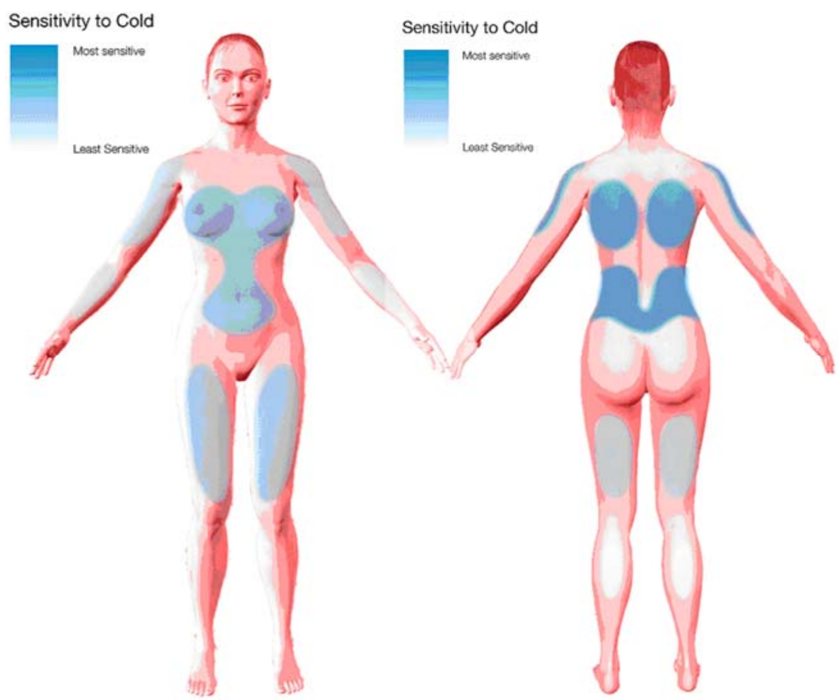

Figure 2. Body zoning to cold – female

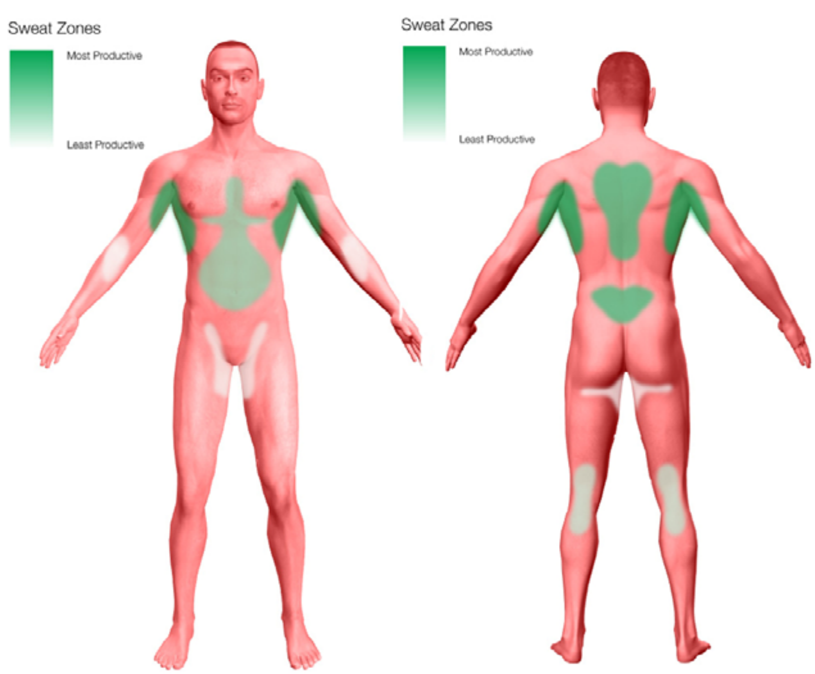

Figure 3. Body zoning to sweat - male

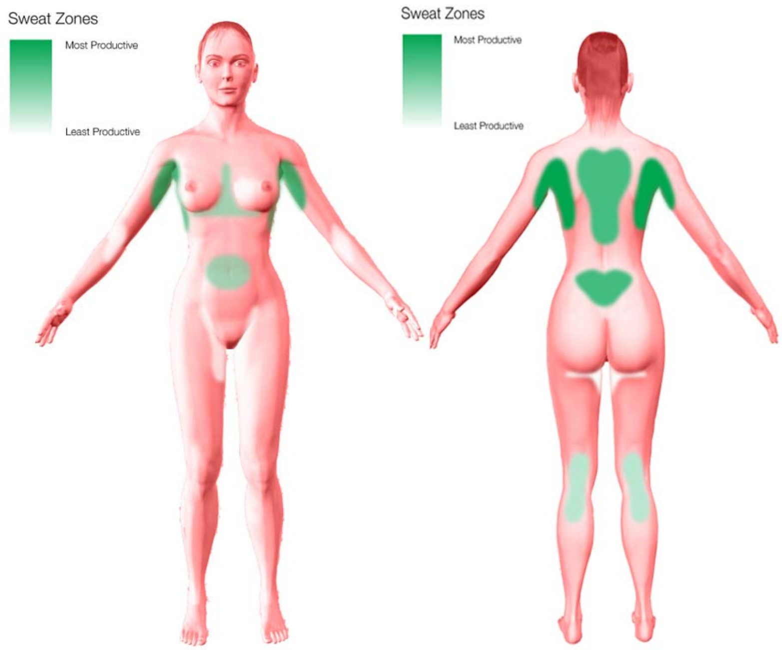

Figure 4. Body zoning to sweat – female

The body images above demonstrate the body zone sensitivities from high sensitivity to low sensitivity. This research used these body sensitivity zones as a basis for Ergonomic Seamfree sportswear engineering.

Very careful investigation was conducted into fibre/yarn selection for the prototype products. The criterion for yarn selection encompasses its physical, thermoregulatory, and moisture management properties; as well as aesthetic, environmental, supply and financial elements.

The yarn performance was also evaluated for knitability, tenacity (mean and CV), elongation (mean and CV) and hairiness (which would affect the pilling performance of fabric). The yarn performance directly affects the quality of the knitted garment and therefore the parameters, such as knitability, tenacity, elongation and hairiness have been identified as critical. When considering the yarn evaluation, the numerical rating of the stated parameters was used to select the most suitable yarn. If two yarns exhibited the same numerical rating the appearance parameters were taken into consideration.

Knitted fabric constructions were developed and tested for thermal; moisture management; porosity; thickness; cover factor; stretch-recovery, power compression ability; and weight per unit area.

The full disclosure of these analysis and evaluations is not detailed in this paper as its focus is on Seamfree garment design and engineering principles.

Shima Seiki WHOLEGARMENT® technology of integral method of producing a garment was selected. The principle of this technology is that tubes are knitted simultaneously for the body and sleeves of a garment. These are spaced appropriately on the needle bed: sleeve-body-sleeve (Figure 5).

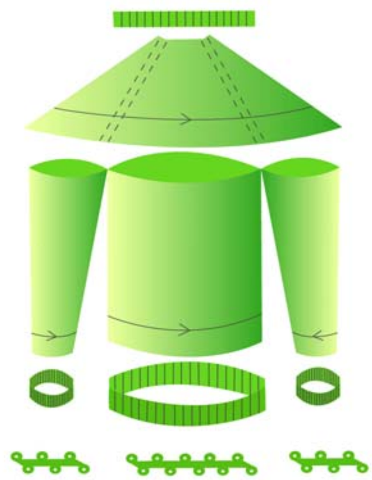

Figure 5. Integral method of knitted garment production. Between each sleeve and the body is precise number of needles: As the knitting of the body and sleeves progresses, these needles are introduced in the sleeve sections one at the time to form the underarm widening. Eventually the sleeves meet with the body and the knitting of three tubes is merged into one. After this, narrowing is performed and then collar is knitted if necessary. The garment described has raglan sleeves but it is possible to generate a wide range of different sleeve heads of the set-in type.

In this research a Shima Seiki WHOLEGARMENT® SWG-X 15 gauge knitting machine was used. This machine is unique, has 4 knitting beds and offers a possibility of incorporating true rib and other double jersey structures into the garment. This allows producing integrally knitted garments with no make up seams and separate zoned sections utilizing different yarns, constructions and colours incorporated seamlessly into the garment. This capability supports the incorporation of engineered performance zones with variable attributes into the garment according to the body zoning.

To produce the seamfree engineered garment range the Concept Product Architecture Map was developed (Table 1).

<table>
<tr><th>Product Segment</th><th colspan="2">Skin Layer</th><th colspan="2">Skin/Middle layer</th><th>Middle layer</th></tr>
<tr><td>Product Items</td><td colspan="4">Tops and bottoms</td><td></td></tr>
<tr><td>Fabric weight range</td><td colspan="2">120-170gsm2</td><td colspan="2">180-250 gsm2</td><td>280-350 gsm2</td></tr>
<tr><td>Utility/Application</td><td colspan="2">Worn against the skin Could be combined with Middle Layer or Outer Layer</td><td colspan="2">Could be worn against the skin or over light weight underwear as a middle layer</td><td>Worn over skin layer</td></tr>
<tr><td>Style Elements*</td><td colspan="2">Fitted silhouette, incorporated structures for zoning, underarm action gusset, cru neck, V-neck; short, 3/4, long sleeve; short, long leg (fitted and flared), crotch action gusset; athletic crop top; athletic full length singlet</td><td colspan="2">Fitted silhouette, incorporated structures for zoning, underarm gusset, cru neck, V-neck; turtle neck with zip, short, 3/4, long sleeve; hood, short, long leg, crotch action gusset</td><td>Relaxed fit, minimal zoning, street-, knitwear-elements/styling; cru-neck, turtle neck with zip, hood, through front zip</td></tr>
<tr><td>Style Categories</td><td>Action Fit-Stretch</td><td colspan="2">Relaxed</td><td>Comfort Fit-Stretch</td><td>Relaxed</td></tr>
<tr><td>Description</td><td>Body hugging/maximum fit/ maximum zoning (structure and colour), intarsia, shaping, action look, action embellishment</td><td colspan="2">Some zoning, fitted silhouette, smart look, minimal intarsia, minimalist embellishment</td><td>Some zoning, fitted silhouette, smart look, minimal intarsia, minimalist embellishment</td><td>Some zoning, fitted silhouette, smart look, minimal intarsia, minimalist embellishment</td></tr>
</table>

Table 1. Concept product architecture map

Measurements used for pattern development shown in Table 2 and table 3.

	MALE		Fitted		Relaxed	
	Measurements, cm	Body	Adjustments	Garment	Adjustments	Garment
	Height	179				
A	Chest	108	-3	105	7	115
B	Waist	99	0	99	7	106
C	Bottom (GARMENT)	110	-3	107	5	115
D	Back length	64	0	64	0	64
E	Back width	50	0.5	50.5	6	56
F	Neck drop	3	0	3	0	3
G	Neck width	19	0	19	1.2	20.2
H	Neck circ	43	0	43	1	44
I	Shoulder to shoulder	54	-0.5	53.5	0	54
J	Shoulder length	19	-2	17	1.9	20.9
K	Armhole Position	49.5	0	49.5	3.9	53.4
L	Sleeve length	63	1	64	2	65
M	Sleeve bottom	18	1	19	3.5	21.5
N	Bottom diff	0	0	0	0	0
O	Collar height	6	0	6	0	6
S	Sleeve width 35 cm from collar	33.5	-1	32.5	3.5	37
P	Back length to waist	46	0	46	0	46
Q	Chest position from top	28	0	28	0	28

Table 2. Male body measurements and adjustments for garments

			Fitted		Relaxed	
	Female	Body	Adjustments	Garment	Adjustments	Garment
	Height	166				
A	Chest	88	-3	85	2	90
B	Waist	70	0	70	2	72
C	Hem width	95	-3	92	2	97
D	Back length	55	0	55	0	55
E	Back width	35	0.5	35.5	2	37
F	Back neck drop	0.5	0	0.5	0	0.5
G	Neck width	13.5	0	13.5	0	13.5
H	Neck circ	34	0	34	1	35
I	Shoulder width	38.5	-0.5	38	0	38.5
J	Shoulder length	14	-2	12	0	14
K	Armhole	39	0	39	1	40
L	Sleeve Length	56.5	1	57.5	1	57.5
M	Sleeve bottom	17	1	18	2	19
N	bottom diff	0	0	0	0	0
0	collar height	4.5	0	4.5	0	4.5
S	Sleeve width 35 cm from collar	28	-1	27	0	28
P	Back length to waist	37.5	0	37.5	0	37.5
Q	Bust position from top	27	0	27	0	27
R	Front neck drop	1.5	0	1.5	0	1.5
V	Bust centre	17				

Table 3. Female body measurements and adjustments for garments

The following style elements were considered and utilised: raglan; modified raglan; epaulet (French raglan); set in sleeve; fitted silhouette; round (crew) neck, turtle neck, high neck and long sleeve. Different structures utilising different yarns and their combinations were incorporated into performance zones of the garments. It was the aim of the research to highlight these zones with colours for visual impact and highlighting "hi-performance" attributes of the garments.

Garments were knitted and finished in a dyeing/finishing lab, at RMIT University, Brunswick campus.

Different treatments and finishing routes were extensively researched and were part of this study.

Finished garments were model fitted, patterns were adjusted, action zoning was adjusted to the model's body zones; and styles finalised.

Fabrics in manufactured prototypes were extensively tested for stretch and recovery both in warp and weft direction as well as for moisture management and thermal properties. The objective of these tests was to evaluate the relative stretch and recovery of the Seamfree fabric when compared with traditional weft knitted 100% wool fabrics currently used in cut and sew skin layer sportswear applications; and conventional nylon/elastane cut/stitch-shaped knitted garments used for skin layer in active sportswear applications. The stretch and recovery in the warp direction is more critical to overall wearer comfort in tightly fitted garments due to the natural propensity for weft knitted fabrics to have a greater stretch in the weft direction. Ideally the “square” stretch is desirable for the skin layer fabric.

This research concluded with wear trials. There were 12 subjects selected for wearer trials: 8 males and 4 females. Subjects were selected to achieve an appropriate cross section of fitness levels, ranging from elite fitness to poor fitness. Each subject was tested in similar environmental conditions. Testing was conducted in both hot and cold conditions. Subjects were tested wearing Seamless and traditional cut and sew garments as a skin layer. Data was compared with subjects wearing commercial branded synthetic cut and sew garment. In both cases identical outer shell was worn over skin layer garments.

Cold conditions were: 1/ +4°C - +7°C
2/ -2°C - -3°C

Time period - two days, trial time – 90minutes (15min warm up; 60minutes exercise; 15min warm down. Exercise activity – cross country skiing in Victoria, Australia.

Each subject was interviewed to assess sporting activity levels and fitness levels. Subjects were required to make comment on a number of issues for each trial session. These issues were

- Fit
- Sensorial skin comfort
- Thermal regulation characteristics: Heat build up; its retention and dissipation for various areas of the body;
- Moisture build up and moisture transfer for various areas of the body
- The comfort of the garments when related to the freedom of movement of the wearer
- The positive and negative impact of body zones in the Seamless garments
- Overall rating of Seamless garments versus the traditional cut and sew garments in each session.

The collected data was analysed, synthesised and number of conclusions were drawn from these trials. The trials are considered preliminary and wider cohort will be required for further research.

Results and Discussion

In this research after conducting the fibre and yarn evaluation, selected yarns were 100% fine Merino wool in count range of 2/60Nm to 2/48 in 17.5µ to 18.5µ; nylon covered elastomeric yarn (44 dtex Lycra & 78 dtex Nylon), Bilorex elastomeric yarns (22dtex Lycra & 17f5 Nylon) and Merino wool 18.5µ covered Elite™ PBT polyester (2/50 Nm x1 Merino wool -94 %, Elite (PBT) 6%; and 2/40 Nm x1 Merino wool - 85%, Elite (PBT) 15%).

The following structures were selected to be incorporated into the garment design: single jersey; jersey incorporating tuck stitches at variable density; single jersey incorporating transfer stitch with various densities of openings created; 1x1 rib; 1x1 variegated ribs; and 2x2 ribs.

As discussed above, sample styles development and engineering, both men's and women's was approached from simple to more complex with the additional introduction of colours. The progression of sample style development is outlined below:

- Plain long sleeve top with modified raglan sleeve;
- Plain long sleeve top with modified raglan contrast colour sleeves;
- Plain long sleeve top with modified raglan sleeve with structural zoning;
- Plain long sleeve top, modified raglan sleeve, structural zoning, contrast colour sleeves

Some styles are illustrated in Figure 6.

Front	Back	Description
		Merino Light - Action Zone. Long sleeve modified action raglan, plain jersey woman's top with structures for body zoning on the body and sleeves. Crew neck, rib 2x2 seam-free trim Structures: single jersey, transfer stitch single jersey, 2x2 rib, 1x1 rib, mesh. Intarsia of the second colour on the sleeves and sides of the body
		Merino Comfort Stretch –Action Zone. Long sleeve modified action raglan plain jersey woman's top with structures for body zoning on the body and sleeves. Crew neck, rib 2x2 seam-free trim Structures as above. Intarsia of the second colour on the front of the body
		Merino Comfort Stretch –Action Zone. Long sleeve modified action raglan plain jersey man's top with structures for body zoning on the body and sleeves. Crew neck, rib 2x2 seam-free trim Structures as above. Second colour body.
		Merino Comfort Stretch. Long sleeve modified action raglan plain jersey man's top with structures for body zoning on the body and sleeves. Crew neck, rib 2x2 seam-free trim Structures as above. Second colour body.

Figure 5. Ergonomic Seamfree Active Sportswear styles

The Ergonomic Seamfree Active Sportswear concept places great emphasis on body contouring and closely fitting designs. As such, sample fit was an integral part of concept design as body contoured fit highlights athletic silhouettes and ensures appropriate placement of the engineered action zones in the garment. In addition, the ergonomic designs of this concept promote ease of movement for the wearer when stretching and strenuous movements are being performed.

Obtaining successful sample fit characteristics for both ladies and men's styles has proven to be a time consuming and at times unrewarding task. Due to the trend leading nature of this concept standard WHOLEGARMENT® style and pattern templates are of little assistance in building correctly styled and fitted garment designs. The result was that much technical time was used in developing the best fit characteristics for both ladies and men's styling. The major reason for this is that the Seamfree WHOLEGARMENT® technology uses very different principles to traditional cut and sew garment manufacturing, therefore traditional solutions to garment fit problems may not be appropriate. The one piece WHOLEGARMENT® technology allows numerous design freedoms, but also places some restrictions on styling. As explained above, the armhole and shoulder lines in an integral garment are formed at the time when the knitting machine performs the transfer of sleeves towards the body. This method places great restrictions on the shape of the armhole and sleeve head due to the limited number of needles that can participate in the transfer action at any given time.

As follows from the above technology constraints, the most significant hurdle of this research was obtaining correctly fitted shoulders; neck and arms for garment styles. This ill-fitting manifested itself in tightness; puckering; ballooning sleeves at the shoulders; and creasing around the neckline. Simplification of styles in the area of armhole and neck has overcome these issues and has streamlined the sample engineering task saving much time and cost, but required a substantial compromise of design ideas.

Another restriction that available seamfree technology places on active sportswear design is that of a limited number of colours that could be used in any one knitted course. Currently the 3 yarn feeders are available for sleeves and body knitting and only two additional feeders could be used for introduction of colour or yarns to the garment for zoning. As evident from Figure 5, zoning was achieved mainly by incorporating various knitted structures into the required zones.
Utilization of garment zoning by incorporating different yarns is restricted by very limited intarsia capability offered by WHOLEGARMENT ® technology. Further development of intarsia

capability would be one of the critical introductions to the current WHOLEGARMENT® knitting technology.

Wear trials of the developed garments were conducted where subject was required to rate the relative performance of the Seamless garment versus the traditional cut and sew garments. A number of conclusions were drawn from this research:

1/ the wale stretch of Seamfree and weft knitted garments exhibited similar characteristics. The introduction of elastane to both Seamless and weft knitted cut and sew garments significantly improved wale stretch. This was shown as an improvement in wearer comfort for all subjects.

2/ Seamless garments exhibited superior comfort where traditional cut and sew seams would normally be incorporated into the garments. This was shown through less chaffing of the skin due to absence of seams; and greater stretch at the points where seams were placed on the cut and sew garments, allowing more freedom of movement.

3/ the incorporation of body zones consisting of different fabric constructions and weights in the Seamless garments was highlighted by the wearers as giving a significant improvement in comfort, when compared to the cut and sew garments. Wearers commented that reduction in moisture build up and heat transfer was improved in the body zoned areas of the Seamfree garments, resulting in greater comfort.

The possibility of garment customization to each uses' body shape and size is important for improved fit and comfort.

The restrictions of the currents seamless technology are most visible in the areas of advanced styling and garment constructions. It is currently almost impossible to modify the shape of the sleeve, armhole and neckline to achieve advanced design appearance. Another critical garment engineering and styling drawback of the technology is a very limited number of different yarns that can be utilized in the same knitting course. This restricts required use of different yarns for garment zoning and colour utilisation for innovative design.

In conclusion, it is clear that seamless flatbed active sportswear has yet to rich its full potential, but the technical benefits of zoned seamless engineered garments combined with comfort and technical performance are obvious.

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