Development of children's therapeutic pressure emitting apparel that addresses sensory integration dysfunction

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Design Enterprise Project Report MDE 501
Submitted in partial fulfilment of the Master of Design Enterprise.
School of Design
Otago Polytechnic
New Zealand
2016

Acknowledgements

I wish to take this opportunity to thank the MDE lecturing team, my main supervisor Sian Griffiths for her advice, assistance and patience. To the staff of the Textile & Design Lab, Auckland University of Technology thank you for making me feel welcome. Special acknowledgement to Gordon Fraser for all his skilled help. Thanks to the Todd Foundation for granting this study a Todd Foundation Award for Excellence (ITP Sector). Jane Venis and George Chalmers for their assistance in getting this report print ready; much appreciated. Thanks also to family and colleagues for their support, understanding and encouragement.

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Image References

Master of Design Enterprise

The Otago Polytechnic, School of Design, Master of Design Enterprise (MDE) is structured in three phases;

Phase 1 is made up of three integrated papers *MDE 401, MDE 402 and MDE 403.* These explore *Design, Enterprise and Operations* through the introduction to and use of frameworks for innovation and methods associated with design-led strategies.

Phase 2 MDE 404 involves an industry placement with which to inform and enhance the direction of each candidate's individual design enterprise project.

Phase 3 MDE 501 Design Enterprise Project requires the research and development of a design enterprise around a new product or service opportunity. The new product or service entity is informed by an opportunity either in conjunction with an industry partner, or alternatively around an individually driven design inspired enterprise.

Introduction

MDE Aim

The long-term aim of this study is to design and manufacture customised contemporary garments for children with sensory integrative issues arising from the developmental disorder named sensory integration dysfunction (SID). These garments principally aim to aid the integration of tactile (touch) and proprioception (body position) for the wearer. It is foreseen in the near future that a therapeutic garment could be commercially produced that allows the wearer to modify sensation, specifically the experience of deep pressure in order to effect sought internal states of change of a physiological, cognitive or psychological nature. This section of the research study specially focuses on the trialling of the garment's design with an emphasis on fabrication.

Context

This topic originated from my personal research into the lack of functional, appealing and discreet clothing for children that addresses the need for specific sensory feedback. This report records my research study to date beginning with a focus on understanding sensory integration dysfunction and existing treatments, in particular methods that provide deep pressure. The framework of a single case study for a client (a child who has sensory integration dysfunction) in conjunction with the use of a functional clothing design process, informs the initial development and testing of prototype garments. These were explored and enhanced through collaboration with the case study participant, their family and therapists.

My personal interest in a client-centred approach to garment design stems from the experience of running a small made-to-measure apparel business in which a number of my clients had physical disabilities. My clients frequently offered possible garment engineering solutions to their individual clothing problems. I enjoyed this collaborative approach to designing and making. I now have a family member with an Autism Spectrum Disorder (ASD). Many of his sensory needs relate directly to clothing. Part of their early intervention therapy included the wearing of a weighted vest, which was unappealing on a visual and practical level. It had a very 'homemade' aesthetic, was ill-fitting and cumbersome for both the wearer and caregiver to handle. This experience motivated me to question the lack of functional, appealing and inclusive clothing for children needing sensory stimulation input from garments.

Figure 1 Made-to-measure

Literature Review

The literature review begins with a consideration of what sensory integration and SID are, before considering the effectiveness of different types of deep pressure sensory feedback as a therapeutic tool.

Sensory integration

The concept of sensory integration developed during the 1960s from a body of work by occupational therapist A. Jean Ayres. The way in which sensory processing and motor planning disorders interfere with learning and daily life interested Dr Ayres (Cribbin et al., 2003). Since then sensory integration theory has evolved into one of the most studied and developed theoretical frameworks in occupational theory (Cermak, 1994). Sensory integration is defined by Ayres (1979) as:

> The organization of sensory input for use. The 'use' may be a perception of the body or the world, or an adaptive response, or a learning process, or the development of some neural function. Through sensory integration, the many parts of the nervous system work together so that a person can interact with the environment effectively and experience appropriate satisfaction. (p. 184)

All the information we receive from our body and surroundings comes to us through our sensory systems. Our seven senses; touch (tactile), movement (vestibular), body position (proprioception), sight (vision), sound (auditory), smell (olfactory) and taste (gustatory), gather information which then enters central processing networks within our brain where it is organised and interpreted (Cribbin et al., 2003). As information from multiple sensory systems is processed reactions to sensory input are graded in an adaptive manner, known as sensory modulation (Miller, 2014). In everyday life, we are not often aware of any one sense as they usually work together and integrate in an automatic way providing us with a sense of who we are, where we are, an understanding of our surroundings and happenings around us and how we should respond.

What is sensory integration dysfunction?

When sensory information from one's body and the environment does not integrate in the brain as it should, or the brain cannot sort out, filter, analyse or organise sensory messages, this is known as SID (Ayres, 1979). As a result, a person experiencing this disability is unable to respond to sensory information in order to behave in a consistent and meaningful way, this can lead to an adaptive response, which may not be beneficial in the circumstances (Cribbin et al., 2003).

Differing terminology is used within the literature to describe and label sensory integration differences, such as sensory processing disorder, sensory modulation disorder and sensory integrative dysfunction (SID). This study will use SID. There are many signs of SID including over or under-sensitivity and reactivity to touch, movement, sight and sounds. There are also co-ordination difficulties, in relation to whole body and/or fine hand movements, as well as complications in organisation of behaviour, such as planning and carrying out everyday activities (Cribbin, et al., 2003). A child with heightened sensitivity to light touch will become anxious and wish to remove themselves from a situation that involves light touch, as they find the sensation threatening and hazardous. They do not have the capacity to self-modulate or alter their reaction to reduce the level of arousal. This perception of a danger results in the child not being able to focus on anything else. They often try to remove the stimulus, or work towards removing themself from it, or even become disruptive. Children living with SID often have other issues such as impaired motor development, a learning disability or nervous system or brain disorders such as autism (Fisher & Murray, 1991).

Sensory processing difficulties exist on a continuum of increasing severity, three distinct levels are portrayed, mild, moderate and severe. Depending on how the person is feeling at the time, individuals may be more easily (or not) aroused and then distressed by sensory stimuli (Heller, 2003).

SID and Autism

Scott Tomchek in his 2005 Doctoral Dissertation 'Characterizing Sensory Processing in Autism Spectrum Disorder' notes:

> The neuroscience literature generally presents material at the level of processes and neural mechanisms, whereas the occupational therapy literature generally conveys information at the level of experience or behaviour. Given the overlap in terminology, bothfields describe and provide evidence of impaired sensory processing in autism (pg.17).

Lucy Jane Miller (2014) also makes comments of co-occurrence of the two distinct conditions ASD and SID within individuals. Miller, a practicing occupational therapist and active researcher, concludes that most (perhaps all) children with ASD have sensory issues. She proposes that a great number of children with SID exhibit symptoms of attention deficit/ hyperactivity disorder (ADHD) as well.

1 person in 100 has an Autism Spectrum Disorder, this includes people who have Asperger Syndrome. The estimated population of people with Autism Spectrum Disorders in New Zealand is approximately 40,000.

http://www.autismnz.org.nz/about_autism retrieved 18/3/16

Somatosensory

SID is commonly classified into specific types by using frameworks to identify levels and relationships within the individual's dysfunction. Miller (2014) defines SID as difficulty with one or more sensory processes, such as detecting and interpreting a sensation, responding accurately, regulating input and output or having a meaningful response to sensation.

This study focuses on the somatosensory context.

Somatosensory is a specific type of dysfunction associated with processing tactile and proprioceptive sensations (Bundy & Murray, 2002). Somatosensory receptors gather sensory inputs from both the tactile and proprioceptive systems determining how the two are working together. This information is then transmitted in parallel to the central nervous system (CNS) for further processing (Gardner,2010). The reception and processing of tactile or touch sensation is dealt with by two systems. We have both protective and discriminative mechanisms. Our protective touch system responds to light and unexpected touch. Our discriminative touch system tells us when we are being touched, what we are touching and in which places.

Proprioception is the sense that gives us an awareness of body position. Messages from our muscles, tendons and joints tell us where we are in space and how our limbs are moving, including the force of movement and effect of gravity (Kranowitz, 2005, Abraham et al., 2015). Sensory information detected from our surroundings by our body through touch receptors is conveyed to our central nervous system for processing, together with nerve fibres that sense our body position, whether static or moving. Somatosensory receptors monitor the temperature of the body, recognise the size, shape and texture of objects and environments and provide information about the perception of painful, itchy and tickling stimuli (Gardner, 2010).

A child with somatosensory dysfunction has difficulty responding to and regulating or modulating tactile and movement sensitivity. Often the behaviours of such a child do not match the nature and intensity of the sensory messages. These behaviours are described in the literature as three sub-types relating to how sensory input is modulated by an individual (Miller, 2014).

1. Sensory over-sensitivity (hyper-sensitive)
2. Sensory under-sensitivity (hypo-sensitivity)
3. Sensory craving (seeking)

If difficulty is experienced processing tactile information in everyday life, a child is considered overly sensitivity to tactile input resulting in withdrawal from, or avoidance of, certain tactile experiences. This defensiveness is opposite to under-sensitivity, which is demonstrated through the seeking out of more tactile input, to give the body what it needs.

When a child has difficulty grading the force of their movements their proprioceptive system is not functioning correctly. Input from their joints and muscles could be over-sensitive or under-sensitive as they strive to regulate their behaviour and stay in control. For example, during fine motor activities such as using a pencil, individual children may either press too lightly or use extreme pressure to make a mark. During gross motor activities such as walking they may prefer to skip and stoop, or appear weak and clumsy bumping into others or objects (Abraham et al, 2015).

Treatment of sensory integration dysfunction

Historically, children with SID (including somatosensory) have been effectively treated by the application of deep pressure sensation to lessen anxiety and arousal. For example, Ayres (1979) reported that wrapping a child with SID in a gym mat produced a calming effect. This is not such a foreign reality; as across most cultures newborns are swaddled, many of us relate to the stress-relieving properties of massage or the security provided by a hug. It is not just those who have significant perceptual problems who show positive responses to deep pressure sensation. Normal adults reported an air mattress apparatus that applied squeezing pressure to the body enhanced relaxation and reduced anxiety (Krauss, 1987).

The somatosensory system carries information from the body to the CNS; receptors gather somatosensory inputs and transmit for processing. Mechanical tactile force applied to the body such as light touch, deep pressure, stretch or vibration are processed by mechanoreceptors that begin the tactile neural transmission. Mechanoreceptors within the skin attend to different types of sensory activation, some respond to the commencement and termination input but not sustained input. They are fast adapting and sensitive to changes in tactile input, in contrast slowly adapting receptors provide the CNS with intensity of touch, duration of touch and the speed of input. Thermoreceptors are also included in the tactile system and interpret temperature input. Proprioceptive input is also carried along somatosensory pathways which define and transmit the perception of joint and muscle movements, as well as position of the body, or parts of it, in space, the force muscles are exerting and the intensity and speed of muscles being stretched. Determining the direction and velocity of body movement, alongside the effort to grasp and lift (pulling) of objects (Lane, 2002).

This project seeks to design a pressure garment that enhances the lives of individuals that seek 'deep pressure' that aligns best with their somatosensory experiences, rather than solely tactile deep touch pressure input. There have been a number of studies that have considered the application of deep pressure sensation as a SID symptom management tool. Most have involved the wearing of weighted or compressive pressure garments (without a self-adjustment facility), by people who repeatedly show either conscious or unconsious sensory feedback seeking behaviour. Researchers have then observed or monitored and reported behavioural change.

Weighted garments and products

Olson and Moulton (2004a) undertook a research study that investigated over 300 paediatric occupational therapists' general experiences and practice with weighted vests. There was an agreement between participants of certain positive behaviours in clients, such as staying seated, remaining on-task and having an increased attention span. Negative behaviours such as heightened activity levels and rocking were frequently reported to decrease. However, Olson and Moulton noted that it was imperative that further studies into the use of weighted vests for children be undertaken (2004a). Late in 2004, Olson and Moulton extended their original study by telephone interviewing a further 51 occupational therapists, who were also questioned in relation to their use of weighted vests. The findings from this study extended those of their previous study. They stated: "Weighted vests were typically recommended to calm children and increase their ability to attend to activities" (2004b, Pg.64).

Fertel-Daly, Bedell and Hinojosa (2001) examined the effectiveness of using weighted vests in preschool children with a form of SID known as pervasive developmental disorder (PDD). Generally, the children's attention span increased while self-stimulatory behaviour reduced. Self-stimulatory behaviours include repetitive, introverted and possibly soothing activity such as looking at light through rapidly flicking fingers. However, they concluded that additional research was needed to build consensus regarding the effects of wearing weighted vests.

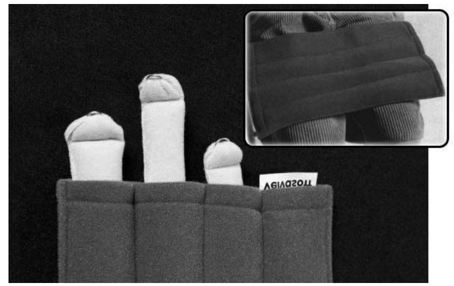

Figure 2 & 3 Weighted vest & inserts

Seven studies examining the use of weighted vests were reviewed by Stephenson and Carter (2008). They noted the limited number of peer-reviewed studies, some of which reported some positive findings, however, they could not recommend clinical application at that point as there was a limited body of research and a number of methodological weaknesses in the studies examined.

Mullen et al., (2008) studied the safety and effectiveness of weighted blankets while participants were lying down. Vital signs were monitored to assess the health status of the adult participants. It was reported 63% of participants had reduced anxiety after use and 78% preferred the weighted blanket as a calming modality. A subsequent study published in 2015 was undertaken by researchers from four of the earlier studies. This study recruited adults who were available because of acute inpatient mental health incidents requiring hospitalisation. The previous studies' results were verified indicating that the use of weighted blankets appeared to provide a calming effect and their use was 100% safe when used by adults (Champagne,et al.).

During 2014 Lin et al., conducted a study of the effects of weighted vests in children with attention deficit hyperactivity disorder (ADHD). The study measured 110 school-age children's attention impulse control and on-task behaviour with the computer based Conner's Continuous Performance Test- II (CPT-II) task. Multipocketed vests that contained 10% of each participant's body weight were worn, doubling the percentage of body weight many previous studies involving children have used. Participants were randomly divided into two groups, the first group completed the CPT-II task wearing a weighted vest, returning to complete the same task four weeks later wearing unweighted vests. The second group completed the computer task in the reverse order first wearing an unweighted vest, and later wearing the weighted vest. All the study participants were informed they were wearing the same vest during both sessions of completing the task. Study results data showed that the participants wearing weighted vests during the CPT-II task demonstrated significant improvements in the frequency of looking away from the computer monitor, leaving the their seat and fidgeting. Data showed no difference in the on-task behaviour of making meaningful or meaningless utterances between the two vest conditions.

Grandin (1995), a Texan university Professor who has autism and sensory integration issues, has described the sensory feedback benefits of a padded and weighted vest, as well as snug Egyptian mummy-type sleeping bags, which provide both pressure and comfort. There are a number of weighted therapeutic products prescribed by occupational therapists to wear or drape on the body that deliver deep pressure sensory feedback. The range includes weighted collars, torso garments, weighted cushions to be placed on a lap while sitting or quilts to provide extra weight while lying down (Therapyshoppe,2016). Many of these items are also available for purchase without a specialist prescription via the internet.

Safety variables

Weighted vests are a commonly used tool by many occupational therapists (Olson & Moulton, 2004a). General safety guidelines exist regarding the use of weighted vests, such as gaining the wearer's consent, that the wearer's vital signs should be observed and that a child wearer will not be left unsupervised. The amount of weight to use and the length of time to wear are informed partly through recommended guidelines of weight for child backpacks. Body weight ratios of 5-10% are suggested alongside distribution of weight and schedules for wear time. (Olson & Moulton, 2004a, Mullen et al., 2008, Stephenson & Carter 2008). Stephenson & Carter 2008 make note that weight within typical 'weighted vests' is more evenly distributed than a backpack, also that consideration needs to be given to the periods of time a weighted vest is worn in comparison to the time a child is likely to be wearing a backpack.

Pressure garments

A case study of a thirteen-year-old boy with severe autism and developmental delay, who received deep pressure via the application of padded and wrapped arm splints, saw a reduction during splint wearing of self-stimulating and self-injuring behaviour. Once splints were removed, he sought alternative deep pressure input by wrapping his arms in fabric and stuffing cloth inside his shirt (McClure & Holtz-Yotz, 1991).

Zisserman (1992) monitored self-stimulatory behaviours, such as the banging of hands together and hitting of surfaces, of an eight-year-old girl with autism while she wore an anti-burn scar pressure garment that provided deep pressure sensory feedback. Both during the wearing of the scar pressure garment and in earlier observations of the child while wearing arm-length gloves made from support pantyhose, the normally frequently evident self-stimulatory behaviour of banging hands together decreased. Zissermann does not recommend the wearing of anti-burn scar pressure garments, however she states that "pressure might be applied in other ways (as well), as appropriate for a particular child" (p. 550).

In more recent research concerning the wearing of a pressure garment, the effects of deep pressure stimulation on physiological arousal was monitored on 50 adult participants whilst they were wearing an inflatable *Vayu Vest*. It was concluded that the deep pressure stimulation provided by the wearing of the vest was capable of eliciting changes in autonomic arousal, and may be useful modality in occupational therapy practice (Reynolds et al., 2015).

Self-administered deep pressure sensation

Temple Grandin is a world authority on the humane management pre-slaughter of farmed animals. Interestingly, Grandin noticed that when cattle are placed in a customised cradle, which restricted them while applying pressure, they calmed considerably. This raised her curiosity. After trying the cattle-system herself, she developed a human squeeze machine prototype in order to self-administer pressure over her own body surface. She observed significant anxiety reduction and increased ability to focus and to tolerate touch (Grandin, 2000).

Figure 4 Temple Grandin's Squeese machine

A pilot study undertaken during 1999 by Edelson, Edelson, Kerr and Grandin, investigated the effects of self-administration of lateral body deep pressure on arousal and anxiety reduction in children with autism using Temple Grandin's Squeeze (Hug) Machine. Two groups of six children with autism were studied over a period of six weeks. The experimental group received deep pressure and the other placebo group did not. The arousal levels of the children were measured behaviourally using Conners Parent Rating Scale (1978) and physiologically using galvanic skin response readings. Their preliminary finding was that deep pressure may have had a calming effect especially for children who are anxious.

As early as the 1970s, researchers reported people with SID calming themselves by seeking deep pressure and that they often preferred to provide this stimulation themselves, frequently avoiding tactile stimulation controlled by others (Delacato, 1974, cited in Edelson et al., 1999).

Market survey

Additional to the weighted vest there are a number of other 'vest' style garments commercially available that claim to help children with ASD, anxiety, musculoskeletal and developmental disorders.

Inflatable vests in various designs make use of the pressure formed by inflating worn garments with air. American based company Therapeutic Systems has engineered the *Vayu Vest* which has an adjustable fit and is inflated through the use of a handheld pump and gauge (Vayuvest, 2016). Two inflatable vests, the *Squease* vest by Squeasewear and the *BearHug* designed specifically for children with autism, anxiety and development disorders, can be inflated by squeezing a hand pump or an automated inflator (Red-dot, 2016. Squeasewear,2016). The *Squease* vest is designed to be worn within an accompanying hoodie or under regular clothing and the *Vayu Vest* when inflated is also low profile enough to be worn under clothing.

Figure 5 Squease vest

Danish company Protac has designed a number of products including blankets and chairs that apply pressure to the body through the use of heavy thickness plastic balls. Their garment solution, *MyFit* vest, is made up of channels filled with plastic balls the size of a tennis ball (Protac, 2016). Elasticated fabric and drawstring ties are adjusted by a dresser to engage the pressure. Neoprene fabricated vests and singlet shaped garments are also commonly used to apply pressure to the wearer predominantly through the adjustment of Velcro strapping (Spioworks, 2016). Tight fitting Lycra® garments are increasingly being used as a treatment modality in children with proprioception and balance difficulties. (Rathinam, et al., 2013). Dress-up themed costumes are available, designed specifically to consider SID issues for pre-school wearers during play therapy sessions (Blacksburg, 2004). Many of these items are available for purchase without a specialist prescription via the Internet.

Refining the research focus

When considering the perspectives of families who live day to day with the reality of SID, Williamson and Anzalone (1997) (cited in Case-Smith & Bryan, 1999) described three important focuses for research.

These are:

1. Helping parents understand their child's behaviour and foster nurturing relationships.
2. Helping parents and teachers modify the environment so that it matches the child's sensory needs.
3. Helping children organise responses to sensory input. (p. 490)

The second and third points defined by Williamson and Anzalone (1997) are of importance to this research. The design and development of a customised clothing item that enables the wearer to address his/her sensory needs by manipulating this garment is a particular focus. The reviewed studies investigating treatment of SID by applied deep pressure have focused predominantly on the use of traditional therapeutic garments rather than comfortable, discreet contemporary wear. What is useful in relation to my study is the generally positive response of participants to the application of deep pressure via weighted or compression garments. However, an anti-scar pressure garment is not easily manipulated by the wearer, as it is difficult to put on and remove. It can restrict movement and is not common in a playground environment. Significantly an anti-scarring garment delivers a constant maximum pressure. This is not an appropriate way to meet the 'squeeze needs' of a child with sensory integrative issues. Any source of constant pressure below pain perception threshold ceases to be registered as stimulation over time and becomes ignored or acclimatised to. This phenomenon is called habituation. To avoid this, stimuli must be applied, then withdrawn, before the perception of sensation is extinguished (Joe, 1998, Zissermann, 1992).

> Watkins-
> "… many of the body's sensory organs, especially those related to the sense of touch, are best able to sense things that are changing and often unable to sense stimulus that is constant, such as constant pressure."

Functional Clothing Design: From Sportswear to Spacesuits. (2015, pg.33).

Utilising clothing to provide deep pressure sensation

During this study, no existing therapeutic pressure-emitting garment that includes wearer adjustable intermittent pressure has been revealed. A need was identified to develop a customised garment that is portable, comfortable, everyday wear. This garment would incorporate a discreet means of self-administering additional deep pressure sensation, as required, and could also be recommended by therapists.

Methodology

After reviewing the relevant literature, it was decided that the most appropriate method of progressing the design and testing of a garment was to have a potential user (child with SID) trial the wearing of a garment as it was prototyped and developed, thus mirroring the process of what would be considered a case study in research terms. An eight-year-old boy with significant SID issues, renamed 'Ben', was identified as his family were interested in the possibility that a garment could help his modulation of certain sensory responses.

This approach was used as central to this study was being able to identify and consider two parallel processes, design of a discreet textile-pressure delivery system within the garment and monitoring of any therapeutic response the garment had on the wearer. The multidisciplinary team approved all procedures and ethical consent for a single case study was approved before participant recruitment.

Single case study

In identifying the research strategy for this prototype garment development, the method of a single-case study was identified as appropriate as this method of study complements the operational structure of the functional clothing design process. Case studies are described by Yin (2003) as having a distinctive place in evaluative research, particularly when describing a contemporary intervention which is studied through multiple methods within a real-life context.

Stake (1995) also emphasised that case study methodology is distinguishable through the combining of the different sources of evidence and methods of reviewing a case. The data collection sources may include structured, semi-structured or open interviews, document and artefact analysis and participant-observations. When varied data collection methods are combined in a case study, triangulation occurs which has the effect of giving the research more validity. (Yin 2003, Stake 1995, Gray 2004).

Gray (2004) describes that a single case study is best suited when it either plays a significant role in testing a hypothesis or theory, or when the case represents a unique, extreme or a revelatory situation. This method of study is of use when there is a need to understand a particular circumstance or problem in-depth, especially when a case is rich in information. A child with SID is unique in their sensory needs, therefore the focus of this study is to investigate a 'particular case', that of the response of the wearer trialling the pressure-emitting garment prototypes. Therefore, for the purpose of this study, the single case study methodology was selected for the initial trial.

Burns (1994) states the case study method enables the researcher to gain a holistic view of certain phenomenon and is useful to conceptualise a continuum ranging from an individual subject to a whole culture. Whatever the subject is, to qualify as a case study, it must be an entity in itself. Burns also notes a clinical case study is an approach often employed when an in-depth understanding of a particular individual is sought which defines a typical case. He refers to a child experiencing reading problems and goes on to note that such case studies usually employ interviews, observations, a review of records, documents and testing, all of which can help gain understanding of the problem and identify possible treatments.

Another feature of linking case study research methodology and design process methods is the ability to redefine the 'case' of ambiguities after collection of initial data. Yin (2003) describes that if this happens within a case study, the researcher may have to backtrack, review different literature and possibly revise the research question. This method of responding to data/feedback is mirrored within the design process because as designs are conceptualised and realised, designers often perform mid-cycle research and/or revisit earlier research, inspirations and ideas. The design as a process is often circular, even spiralling off as the evaluation step generates new directions of investigation.

The case study method also helps focus the designer's step-by-step direction (design process) clearly on the user. Curedale (2014) in his book Design Research Methods supports the definition of a clinical case study involving an individual person who is studied in-depth, predominantly through interviews and observation. Curedale recommends the case study as a practical research technique, if the context is known, the user is known and insights into the development of a 'design' are required. This is apparent in this study as the environments within which Ben will most benefit from self-controlled delivery of pressure are defined early within the process.

Design process

A user-focused design process is a set of actions or methods carried out in a series, or in steps, which progresses from the initial idea or identified need to an evaluation of the completed design that fulfils the need of the user. Jones (1992) identifies there are many design process frameworks to select from, but gives emphasis to the principle "choose whatever method will tell you what you don't know, but need to know, in order to proceed." (Jones,1992. Pg xx).

The field of clothing and textile design has adapted and developed design process methodologies to best meet the need of apparel design, specifically with a focus on the wearer's environment, activity and the process of working towards making designs more responsive to the wearer's needs (Harr, 1998, Watkins, 1984, Watkins & Dunne, 2015).

FIGURE 1.1 The design process. The design process may (A) proceed in a linear fashion; (B) be continually repeated in a circular fashion; or (C) return at any stage to refine prior steps.

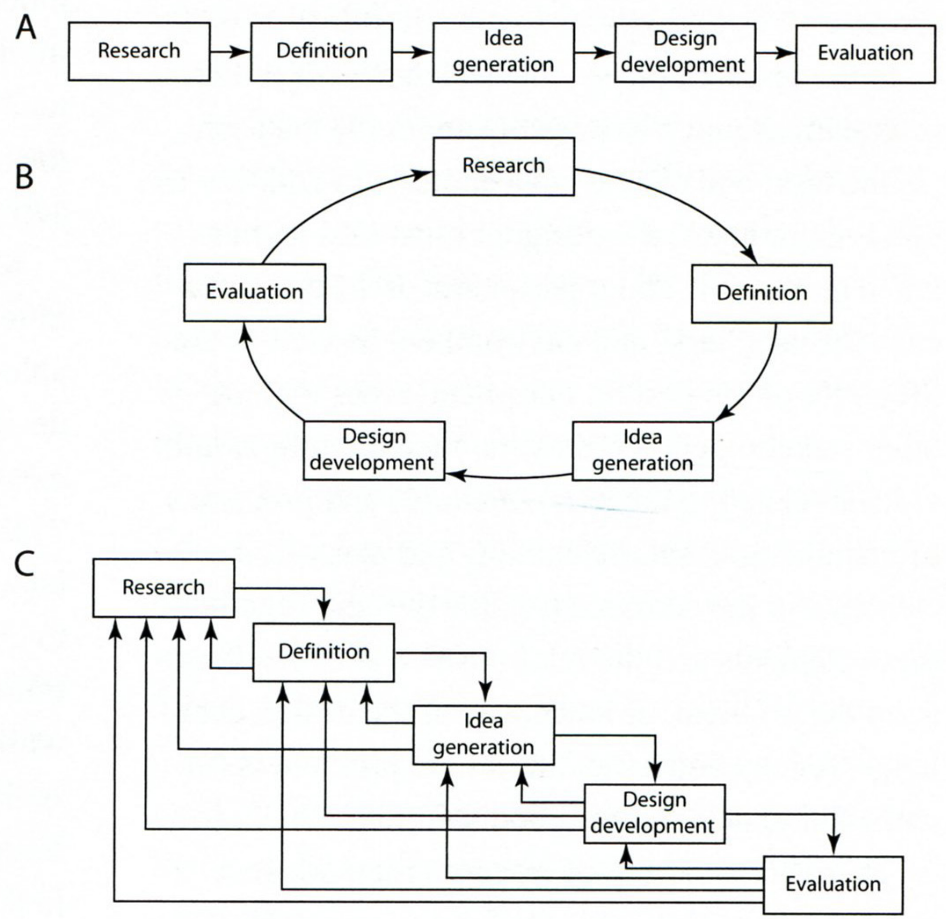

Figure 6 Watkins design process

The functional clothing design process was initially outlined by American apparel design Professor Susan Watkins (1984) in *Clothing: The Portable Environment*, then revisited in the 2015 publication Watkins co-authored with Lucy Dunne, *Functional Clothing Design: From Sportswear to Spacesuits.* The functional clothing design process as outlined by Watkins originates with a demand for clothing to meet a specific need. Watkins developed her problem-solving design process to help students engage in apparel design. Her adapted process to clothing design is based on a design process by J. Christopher Jones. Watkins places substantial emphasis on user needs which requires the designer to have a full understanding of the user, the environment and the activity before beginning the design (Watkins,1984, Watkins & Dunne, 2015).

Once the creative problem is identified and defined, the functional clothing design process outlines a design solution that is thoroughly explored through as many directions of possible investigation. These include literature searches to find out more about

TABLE F.1.
FUNCTIONAL CLOTHING DESIGN PROCESS AND STRATEGY SELECTION

	2 Design situation explored	3 Problem structure perceived	4 Specifications described	5 Design criteria established	6 Prototype developed	7 Design evaluation
1 Request made	1.2 State general objective Brainstorming User interview and observation Visual inconsistency Literature search					
2 Design situation explored		2.3 Brainstorming Observation analysis Market analysis Literature search Identification of critical factors Definition of problem				
3 Problem structure perceived	3.2 Brainstorming Visual inconsistency Reassess critical factors		3.4 Activity assessment Movement assessment Impact assessment Thermal assessment Social-psychological assessment			
4 Specifications described	4.2 State objectives Check specifications against objectives	4.3 Reassess critical factors		4.5 Charting Ranking and weighing Prioritizing		
5 Design criteria established	5.2 State objectives Check criteria against objective	5.3 Identify critical factors	5.4 Literature review of assessment areas to check specifications		5.6 Materials testing Technique evaluation Brainstorming Creative integration Solutions weighed against criteria	
6 Prototype developed	6.2 Visual inconsistency Identify objective User interview	6.3 Identify critical factors	6.4 Literature review of assessment areas	6.5 Rank order specifications		6.7 Specification testing User satisfaction

Figure 7 Watkins-Functional Clothing Design Process and Strategy Selection

the problem range, observations and interviews involving clients/users in real-life environments which help identify user preferences and tolerances. Existing clothing designs are reviewed through a market survey. The data collected from these varied assessments becomes design criteria. Garment specification priorities are set and sometimes discovered through the ranking of design criteria. Prototype garments (Toiles) are developed and wear-tested, to assess whether they meet the established criteria. A prototype is evaluated for effectiveness. Watkins highlights that the design process may proceed in a linear style, be continually repeated in a circular manner or return to any stage to refine prior steps (Watkins, 1984, Watkins & Dunne, 2015).

Lamb and Kallal (1992), also apparel design educators, have developed a model for assessing apparel user needs and wants emphasising the development of creative thinking, as advocated by Watkins (1988). The needs and wants of the user are assessed, informing the identification of the creative problem and design criteria.

Functional, expressive and aesthetic (FEA) user needs are considered.

> We realized that we wanted a general framework that could be applied to design of any type of apparel, including garments intended for people whose needs are not routinely met in the marketplace and therefore have been considered special. (Lamb & Kallal,1992, p.42).

At the core of this model is the intended target customer. Clarification is sought through research into user needs and wants within the context of the intended environment and activity. Culture encircles the target customer in Lamb & Kallal's FEA consumer needs model. Lamb & Kallal (1988) state "Culture influences what users consider as acceptable options for resolving various design problems" (p.43). Designers must be aware of cultural beliefs when developing a user profile and defining their needs. Functional considerations relate to utility, such as protection required for the use-situation, thermal and tactile comfort, overall fit and ease of movement.

Expressive considerations require the designer to be aware of the message the garment is communicating about the wearer. Aesthetics deals with the 'beauty' of the garment and use of design elements such as silhouette, texture, colour and pattern.

Lamb and Kallal (1992) point out that their FEA Consumer Needs Model can be applied to existing design process models as features can be combined at the problem identification stage as the designer defines the FEA criteria for the target consumer (user) in the context of the problem situation. Later during the toile evaluation process each prototype is judged on success in meeting the functional, expressive and aesthetic needs specified for the garment. The combination of Watkin's functional clothing design process and Lamb and Kallal's FEA Consumer Needs Model means the garment design is likely to meet the design criteria established for Ben.

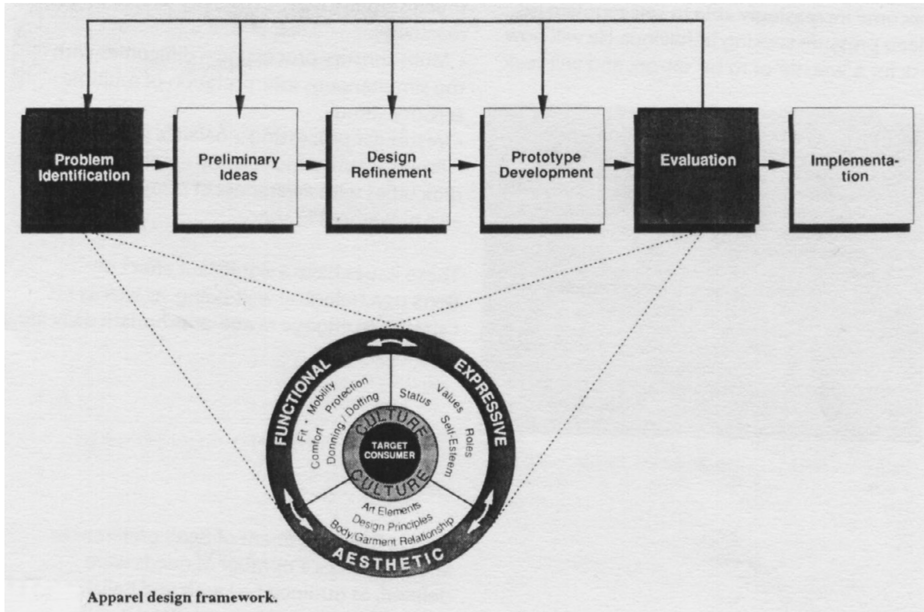

Figure 8 Combination model

Needs assessment

Watkins begins the functional clothing design process with a request/problem to meet a specific clothing need. This user-centred problem is thoroughly explored from as many different directions as possible to define the problem (Watkins, 1984, Watkins & Dunne, 2015).

The initial problem identified in this study was the absence of contemporary wearable and discreet therapy garments that address this particular child's (Ben's) current sensory integrative issues. To gain an understanding of Ben's needs, data was collected through document review, observation and interviews.

A number of documents were reviewed which included Ben's diagnostic history and his relevant health and education assessments. Of particular relevance were those referring to his therapy needs written by occupational therapists, physiotherapists and speech and language therapists. Most informative was the report written by Ben's occupational therapist summarising his sensory profile questionnaire (completed by his parents) and an account of her professional interpretations of Ben's sensory behaviours and needs compiled during home, school and clinic visits, followed by sensory recommendations.

Additional to the retrospective document review, observations were conducted in a number of the environments Ben frequented regularly. Speech and language sessions, sensory room clinics, gymnastics club, school and his home. An effort was made to be as unobtrusive as possible and notes were made immediately after each observation. Anecdotal discussion with Ben's therapists, teachers and family often occurred during observation periods as I sought clarification around some of his behaviours. Informal interviews took place at school with Ben's teachers, at home with family members and with his occupational and speech and language therapists in their respective clinics. Questioning focused on Ben's clothing preferences and dislikes, types of clothing that had been used as part of sensory integration therapy and Ben's response to their use.

Ben's parents and teachers have observed that Ben craves deep pressure and seeks out activities that fulfil this need. He is often seen hugging or pushing into caregivers, peers and furniture, or crawling on all fours. He particularly enjoys being in small spaces, such as boxes, cupboards or under his desk at school and often squeezes between mats and pillows. When stressed, he can be invited to participate in calming sensory activities. With encouragement he will engage in carrying or pushing heavy objects. He appreciates a firm bear hug, deep pressure massage, joint compression or being allowed to retreat to the comfort of being under heavy pillows. These activities have been suggested by his occupational therapist. Together, the multidisciplinary therapy team (which includes occupational therapist, speech and language therapist and specialist teachers), as well as classroom teachers and parents, have devised a sensory diet that assists Ben to reach and sustain desired levels of arousal, in order to be able to function maximally in daily life, at school, in his therapy settings and at home. This includes garment recommendations and the use of therapeutic media such as a weighted vest. As Ben has gotten older he has become increasingly able to self-regulate his deep pressure seeking behaviour. He will now ask for a 'wrestle' or to be 'sat-on' and will seek out small spaces when necessary.

Figure 9 Child seeking deep pressure

Sourcing data through varied qualitative methods (document review, observation and interviews) enabled the triangulation of the data. It was concluded that Ben's sensory integrative issues are complex. They can be summarised into the following categories:

- Touch processing – abnormal perception of touch stimuli (hyper-sensitivity as well as low reactivity).
- Multi-sensory processing – difficulties with the simultaneous interpretation of multiple sensory stimuli.
- Vestibular processing – balance problems.
- Proprioceptive modulation – perceptual difficulties with awareness of body position and movement in space.

These issues have a significant effect on Ben's psychological well-being as well as his capacity to engage in age-appropriate daily life activities.

Creative problem and design criteria

During the assessment of Ben's preferences and tolerances a number of needs were defined as outlined by Lamb and Kallal (1988) in their FEA consumer needs model. Multiple concerns to address for the apparel product were highlighted as functional, expressive and aesthetic considerations. Functional considerations were the most dominant as a clearer definition of the user-centred problem formed design questions.

How can a garment be customised to best address Ben's sensory integrative issues arising from his experience of somatosensory, as well as his needs as an active, eight-year-old child?

Ben's mother reported his preference for firm-fitted clothing, particularly on his torso. She found the weighted vest helpful if Ben was experiencing anxiety and hyperactivity. However, it was sometimes more practical to physically compress or 'squash' Ben rather than add extra clothing during a period of agitation. Once compressed, he would become calmer and usually return to task.

The questions then are:

- Can a customised piece of clothing meet sought deep pressure needs using fabric pressure rather than weight to provide this feedback?

The work of numerous researchers, such as Krauss (1987), Zissermann (1992), McClure & Holtz-Yotz (1991) and Edelson et al. (1999), indicate that applied pressure addresses squeeze-seeking needs effectively. Using pressure, rather than a weighted garment, has the advantage of being practical outside the therapy environment as it is invisible and more readily adjustable.

- As deep pressure seeking behaviour varies in frequency and intensity (of sought feedback) within each individual, how can a garment address these issues?

Ben's need for pressure is a constant feature in his day, however, time spent sourcing feedback as well as the quantity or intensity needed has been observed to vary greatly over the course of the day. To solve this problem an adjustable system that Ben can control is required. This will circumvent the problem of habituation or acclimatising to sensation as pressure will be applied and then released, allowing the beneficial effects of pressure to be optimised.

- Can the amount of pressure delivered by the garment be assessed?

In order to obtain a full and objective assessment of a customised garment's effectiveness, a baseline measure is required of the passive compressive pressure delivered to the skin by the garment's inherent or 'at rest' fabric tension. 'At rest' tension means tension of the fabric alone without the inclusion of additional self-administered pressure.

A measuring device called the *Textilpress*, developed by the Tricotextil Institute in Poland, utilises an ingenious indirect means of assessing compressive pressure (Bogdan, 2006). Maklewska, Nawrocki, Kowalski, Andrezejewska and Kuzanski (2007) found this tool highly valuable when investigating the actual pressure delivered by pre-rated compressive pressure textile dressings used to prevent scars. A cylinder comparable in size to the relevant human body part was covered in neoprene to simulate the skin's surface. A band of knitted elastic fabric sized according to the parameters of La Place Law will have the same compressive pressure against the model's neoprene skin as that of a pre-rated burns dressing when worn on a cylindrical body part of the same diameter. La Place (1806) (cited in Maklewska et al., 2007) established that pressure equals tension divided by radius $P = T \div R$. If the diameter of a cylinder increases, as occurs when a child's chest and hips grow wider, but the tension is not increased, for instance, as they continue wearing last year's swimsuit, the garment's compressive pressure against the skin at the now expanded sites will be lower. This is because the textile fibres are stretched to cover a wider area (Liu et al., 2006). Using the La Place equation, variations in body circumference can be accommodated by manipulating the fabric quantity so that the delivery of pressure can be kept constant. The *Textilpress* uses a sophisticated matrix system to provide an indirect measurement of pressure and is ideally suited for use with children as it does not require they keep still (as in a direct method of baseline assessment).

In addition to baseline measurement, a wearable and built-in pressure assessment tool is required in order to monitor pressure delivery at specific body sites when in use and in situ. This will prove more difficult as the proposed tool requires the worn garment to be wired to a computer for load analysing. A flexible elastomeric textile that is pressure-sensitive, such as *Dynacon C®* (Dynacon Industries, Leonia, New Jersey, USA), has a conductive substrate. When compressed, its electrical conductivity increases (Watkins, 1984). Sensors can be made of aluminium film placed either side of a piece of *Dynacon C®*. When insulated they can be incorporated into the child's garment. The conducted impulse is read and then the load analysing programme calculates the pressure being administered to the body surface in kilograms per centimetre squared (Watkins, 1984).

Garment specifications

Watkins and Dunne (2015) state specifications that arise from assessment of wearer activity in a regular setting is less likely to result in a garment design that interferes with a wearer's tasks and it may even assist their functioning.

The following specifications were initially devised for Ben's customised garment:

- Firm form-fitting upper body garment to be worn under school uniform.
- Smooth, soft handling, firm fit and shape retentive fabric.
- Additional in-built support across Ben's shoulders, chest, back and hips, utilising compressive force rather than applied weight.
- Allowing full range of movement.

Elasticated fabric

Prioritising the design criteria ready for prototype development, as described by Watkins & Dunne (2016), involved further research into 'how' textile tension could meet Ben's deep pressure needs.

Fabrication solutions and appropriate construction techniques were the next logical step of my process. Gaining a better understanding of the application of pressure to the human body began by focusing on the use of pressure bandaging for burn injuries.

Elasticated pressure garment treatments for burn injuries developed more than 70 years ago, following observations from the early surgical principle of bandaging or splinting burn injuries to help reduce the resulting red and raised hypertrophic scarring. The application of pressure garments is not limited to treatment of burn scarring. They are also used in the management of lymphoedema and reducing oedema (excess fluid) in the early stages following a limb amputation (Pratt & West, 1995).

The application of mechanical pressure through the use of elasticated tubular bandage, stockings and garments has become the most commonly used method of treatment to minimise the effect of burn scarring. A number of reasons are identified by Pratt & West (1995) including that they are easy to apply, have minimal disruption to activity for the wearer and they are commercially available.

Studies (Pratt & West, 1995, Macintyre & Baird, 2006) involving the wearing of elasticated scar pressure garments have reported pressure exerted by garments varies and appears to be dependent on three factors - shape of the body parts, type and age of the fabric used and design and fit of the garment. Pressure exerted by garments is known to vary with the design and construction methods. Occupational therapists Joanne Pratt and Gill West in their practical manual on the design and fabrication of pressure garments state:

> Designing and making pressure garments is a technical skill to which the old maxim 'practice make perfect' applies. You will need to have knowledge of basic mathematics and some sewing experience. Before making garments for patients it is advisable to make several for yourself and colleagues. (pg.22)

The fabric typically used to make pressure is weft-knitted Lycra®, which has the greatest stretch in one direction, positioned to correspond with the body's circumferential measurements to achieve the best pressure application. Seaming sites have increased the pressure, therefore the 'bulk' of seams are located on the outside of the garments. Pratt & West recommend:

> A very close, narrow zigzag stitch of no more than 0.3cm is used to join seams. No space between stitches should be visible. Flat seams are used on weight-bearing surfaces… These are made by overlapping the fabric sections by 0.5cm and sewing them together (pg.28).

Knit fabrics are created by inter-looping yarn with each loop anchored to the stitches beside it and caught in the row above. As the fabric stretches the loops expand. There are two basic types of knitting, weft and warp knitting. Weft knitting is a method of making a fabric in which the yarn forms horizontal rows of loops (stitches) across the fabric, approximately perpendicular to the selvedge of the fabric. One horizontal row of loops is made from one or very few yarns. Warp knitting is a method of making a fabric in which the loops are made from many warp threads running along the length of the fabric approximately parallel with the selvedge of the fabric. One horizontal row of loops is made from many yarns (Humphries, 2004).

Richardson (2008) identifies an important aspect of understanding knit fabric is to note the direction of the stretch and how that is considered when creating garments. Most knits stretch more in one direction than the other. The number of directions that knit fabric stretches is used as a way to describe it. One-way stretch fabric stretches as the knitted loops expand horizontally across the fabric. The stretch is entirely derived from movement in the stitches. Garments made from one-way stretch are best fitted with the stretch going around the body. Two-way stretch is fabric that stretches across as well as up and down and the stretch is derived from both the yarn and stitches. Textured and crimpled yarns are knitted creating a spiral formation which uncoils as it is stretched, within each looped stitch.

Figure 10 Second Skin garment for burn scar management

Four-way stretch is fabric that stretches across as well as up and down the fabric, plus it has additional supplementary stretch added through the spandex fibre which is blended with the fibre of another yarn such as nylon, cotton or wool before knitting.

Spandex is a synthetic elastomer which is capable of stretching up to seven times its original length and can then recover immediately to its pre-stretch length once tension is released. The

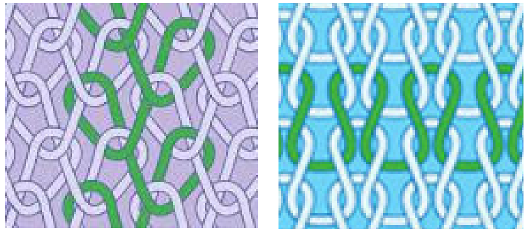

Figure 11a Warp knit structure & 11b Weft knit structure

ability to provide a power stretch makes it an ideal fibre for inclusion in garments that control, support or compress the body during wear. Spandex was originally developed by DuPont and released during 1958 under the trade name Lycra®. Lycra® continues to be associated with products that offer the wearer comfort, fit and freedom of movement (Humphries, 2004).

For ready-to-wear garments such as pants, tops and dresses, the built-in stretch of knits are utilised by the direction of stretch encircling the figure. But for clothing such as bodysuits and leotards or any garment that passes through the crotch, the greatest degree of stretch is best going up and down the body to allow for maximum mobility.

Two-way and four-way stretch patterns are usually identical, meaning the same patterns may be used interchangeably. However, garments such as leggings are best made from four-way stretch as two-way stretch tends to sag and bag especially around the knees and seat. This is because the two-way stretch elasticity does not have any 'memory' meaning the garment will not return to its original constructed shape after wear.

Toile development

The outcome of establishing clear design criteria prepares for prototype/toiling development (Watkins, 1984, Watkins & Dunne, 2015).

Figure 12 Toile 1 back

Figure 13 Toile 1 front

Toile 1 user trial

A singlet-shape garment was selected as it allows the addressing of the particular areas of Ben's body where deep pressure is most frequently sought. It is also inconspicuous under his school uniform. Smooth soft handle Lycra®/nylon fabric was selected for its four-way stretch capability, non-restrictiveness, good recovery from stretch to ensure better shape retention and application of pressure.

Soft non-roll woven rubber/elastic strips were directly sewn to the inside of the garment crossing the torso in lines and forming an 'X' shape both front and back which delivered compression to the chest and back but avoiding the stomach. These are body areas where additional sensation is frequently sought by Ben. Elastic was chosen for its strength, stability, shape retention and laundering qualities. Strips of elastic were also placed around the chest region below armpits and at hip-line level to further stabilise the garment and help prevent 'ride-up' during wear. This was a rapid prototype testing of the initial fabrication and placement of compression. Construction of the toile was minimal only joining the garment at side and shoulder seams. Hems, armholes and necklines were left raw with a cut edge. Watkins and Dunne (2015) advise evaluation of emerging concepts in a physical form (wearable toile). They also point out:

> …it is often more effective for designs to be evaluated in very obvious unfinished or low-fidelity form. This helps the designer communicate to the user that the design is not finished and that it is still acceptable to implement changes. (pg.27)

Initially Ben wore the garment for a short period of time during a fitting and his response was 'Cool, Mum, it's squashing me.'

Toile 2 user trial

Following the initial fittings, placement of the chest-positioned elastic strapping was altered and shifted further down the garment to avoid 'pinching' under Ben's armpits. The garment was trialled in various environments, firstly at home where it could be removed quickly if Ben became uncomfortable. After a number of short half an hour to one hour wear times, including to therapy sessions, Ben was happy and comfortable to wear the toile to school. Dressing assistance was required as on/off ease was less than desired. Ben had difficulty lifting his arms above his head and pulling the firm garment over his shoulders. Ben wore the garment most days during a ten-day trial period.

As expected, deep pressure effect was noticeable initially and then of less consequence over time due to habituation. As Ben still sought additional feedback in the classroom environment, garment adjustability appeared to be essential. This garment delivered equal compressive pressure front and back. Observations of Ben's enjoyment of supine postures (lying on back) suggested increased pressure on the upper back and shoulders could be beneficial. When the garment was removed, indentation of the seamed areas was obvious on his skin surface for a few minutes after removal. Consideration of seaming techniques needed refinement and the traditional knit garment industry practice of using four thread overlocking needed further consideration to reduce bulk.

Additional garment specifications

- Wearer controlled method of garment manipulation
- Smoother, softer seaming techniques

In order to facilitate garment manipulation, the following design alterations were incorporated. A system of pressure delivery was adapted and trialled. Lengths of elastic strapping were draped over Ben's shoulders crossing in an 'X' at his front and back. Both lengths of elastic strapping were increased so they hung loose where they met at hip level on Ben's sides. The extra-long hanging lengths enabled Ben to pull the strapping ends, resulting in a self-administered 'squeeze' across his shoulders, back and chest. Ben enjoyed this control and pulled forward from his body until his arms were straight and the elastic strapping was gripping his body.

Figure 14 'X' placement

Toile 3 user trial

To improve the delivery of deep pressure sensation to the back of Ben's body the elasticated 'X' shape on the back of the garment was altered so that two strips now sat perpendicular to the shoulder blades and joined the chest band of elastic at 90 degree angles. The elastic below the chest band formed an 'X' shape. The crossing point is the mid-back (lower thoracic) region.

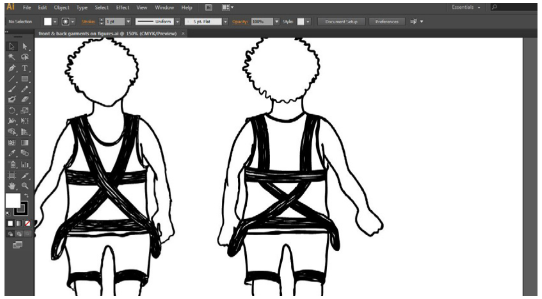

Figure 15 Toile 3

Toile 4 user trial

Once the placement of the elastic straps was successfully altered the next toile was constructed. In this version, elastic was placed on the outside of the garment within a satin ribbon casing. This was to assist in sliding of the strapping whist being activated by the wearer via a 'handle' length of strapping protruding from casing at the side of the garment at hip level. Construction techniques were changed from overlocked seams to cover seamed. Cover seaming results in a much flatter finished seam, more like a traditional flat zig-zag seam which is less likely to create impressions in the surface of the skin.

Figure 16 Toile 4 back

The joined elastic strips of the handle formed a 'V' shape, which Ben can grasp and pull to increase the amount of sensory feedback delivered to the front and back of his body. He can adjust the pressure delivery with the strength and direction of his pull. In addition, by activating upper limbs Ben gains valuable proprioceptive feedback and a satisfying feeling of working muscles and joints. This strapping system serves a dual purpose, giving pressure where needed and providing a stable support structure on a Lycra®/elastic combination garment. These modifications proved successful. When Ben used the handles he reported firm, direct pressure across his shoulder blades and back. He told his parents he was 'transforming.' This comment relates to 'Transformers' which are popular concept toys that transform when manipulated from robots to sleek mechanical objects. This was delightful feedback for all of us.

Watkins and Dunne (2015) describe testing of prototypes by users as crucially important and recommend wear testing as early in the functional clothing design process as possible and as often as possible. They give two reasons. The first is integration of the user's perspective throughout the design process, which allows the prevention of inaccurate assumptions becoming design decisions. Secondly, design alternatives are evaluated objectively by a non-designer early in the process, avoiding the designer becoming too attached to design ideas that do not meet the identified design criteria.

Ben understood immediately how to operate the garment handles to tighten the singlet at will. His delight was obvious. He was also able to utilise the handles without prompting. Ben showed enthusiasm for his customised garment, selecting it to wear when given choices. Definition of seam placement on Ben's body was much less evident as a result of the cover seamed finish. His parents appreciated that a therapeutic garment could be completely discreet. Significantly, Ben sought less additional deep pressure stimuli while wearing his garment and seated in a classroom situation. When engaged in outdoor activities it appeared helpful but a little less effective, as he still sought direct physical contact from his peers and adults. However, this behaviour may also have a communicatory function.

Parents, teachers and therapists observed and reported anecdotal accounts of improvements in Ben's functioning and well-being. While Ben was wearing the garment during the two week trial period, his teacher aide observed his attention span increased, his concentration improved and he remained on-task for longer periods. Over this period Ben engaged more purposefully in one-to-one and group activities, completing more set work. Parents and teachers were thrilled with his progress. Ben enjoyed the resulting acknowledgement. Periods of anxiety, tantrums and non-compliance with requests reduced, which everyone appreciated. Ben was choosing to wear his garment most days.

Toile 5 user trial

Since the initial trialling, a number of the pressure emitting singlets have been constructed for Ben. In addition to the enlarged sizing to fit the growing boy, design modifications have also been made. The garment has been cut to include shaped form- fitting side panels which achieved a more streamlined appearance and resulted in the removal of the hip level horizontal strapping. This alteration resulted in a more intense 'hugging' of Ben's torso. Elastic strips in the 'X' crossover continue to provide the self-organising system, whilst maintaining Ben's movability.

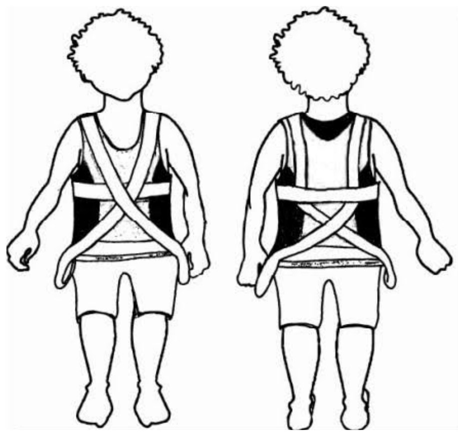

Figure 16 Toile 5

The ribbon casing has been replaced with smooth handle Lycra®, resulting in the whole garment returning more evenly to its original size and shape after the internal elastic strips have been pulled by Ben. Unfortunately, these elastic strips have a limited recovery lifetime as they progressively soften and lengthen, eventually becoming slack and ceasing to provide the desired pressure.

Watkins and Dunne (2015) suggest the evaluation step of the design process involves either the rating of numerical data collected during a study or the less formal subjective opinion of a designer. In the field of functional clothing design, evaluation is usually the less formal option, including methods such as observations, interviews and field testing. If goals are clearly defined as design criteria, evaluation is also clear. This holds true for previously specified functional, expressive and aesthetic needs as defined through the Lamb & Kallal's (1992) FEA consumer needs model.

Fabrication of contemporary pressure-providing textiles

Observations of the inclusion of pressure emitting textiles within sophisticated sportswear led to the next stage of my studies - design research derived from the advances in textile and garment technologies within contemporary sports apparel. A relationship between athletes wearing compression garments and their muscle performance has been the focus of a number of studies (Shishoo, 2005). Shishoo's review of research findings consistently shows wearers of compression garments have increased accuracy of perception of movement (proprioception). Vestibular sense is also helped through wearing compression garments and subjects described a better sense of where they were and how their body was moving and positioned in space. It is noted the Lycra® elastane fabric '… does this by exerting subtle pressure on the nerve receptors in the skin, muscles and joints' (pg.216). The type of compression garment and amount of Lycra® did affect responses. Garments need to include enough compression to enhance perception while retaining mobility. Optimal sports compression garments are also utilising elasticised knitwear construction techniques. Wear comfort is achieved through a blending of fibres (nylon and Lycra®) and knit structures (rib and honeycomb) that are soft to the skin. High-tech seamless whole garment knitting technologies teamed up with three-dimensional body scanning and modelling enables precisely engineered garments.

I identified that a logical step for this project was to cross over into a more commercial apparel environment which would allow the uptake of high-tech fabrication and construction methods currently operational in the development of whole garment knitting technologies and consequently enabling precisely engineered garments. The Textile and Design Laboratory (TDL) at the Auckland University of Technology (AUT) was identified and formalised as a suitable industry placement for my MDE 404 Design Led Enterprise industry placement. It is envisaged through collaboration I will be able to further develop and test knitted pressure emitting garments and access production capabilities and commercialisation opportunities.

MDE 404 at TDL

My MDE 404 industry placement explored utilising the Textile and Design Laboratory (TDL) which is located within the Faculty of Design and Creative Technologies at the Auckland University of Technology. Opened in 2006, the TDL was funded through the New Zealand Government 'Growth and Innovation Pilot Initiative' (GIPI) scheme. In addition to this Government support, the TDL has established educational partnerships with a number of New Zealand tertiary education providers including Otago Polytechnic. Alongside education partnerships, fashion, design and manufacturing industry associations such as Textiles New Zealand, Fashion Industry New Zealand (FINZ), Designers Institute of New Zealand (DINZ) partnered with the TDL to support the key TDL objective of contributing to the growth and development of the New Zealand fashion and textile industries. The laboratory is now well established around digital design, knit and print technologies and supports both knowledge sharing and research (TDL website 2013. Joseph, Smith, & Heslop, 2007).

Figure 18 TDL @ AUT

TDL Staff

Associate Professor Dr Frances Joseph is the Director of the TDL. She co-authored the 2006 GIPI grant application which was successful in establishing the laboratory. Since leading TDL's strategic and research development, Frances has become co-Director of Colab which is AUT's Creative Technologies Research Centre. Innovation through design and new technologies is the focus of Frances's research, especially in the areas of interactivity, e-textiles and design research methodology and creative entrepreneurship.

Dr Mandy Smith is co-Director of the TDL. Her research focus areas are within fashion and textiles and she works at the craft/technology interface. Specialising in seamless knitwear, Mandy is a senior lecturer in the Fashion and Textiles, Art and Design and the Design and Creative Technologies faculties at AUT.

Another colleague, Peter Heslop, has managed the TDL since it opened in late 2006. Peter has a Master of Textile Technology from Bolton University in the UK. He has worked in a number of textile sectors around the world over the past 30 years, including cotton classification in South Africa and denim fabric sales in Northern Europe. Peter is also currently on the board of Textiles New Zealand which comprises of four sections of textile based industry; carpet, footwear, apparel and textiles. Alongside national involvement, Peter also represents New Zealand as a committee member on the Textile Institute's New Zealand section. The Textile Institute, incorporated in England in 1925, has a Royal Charter as a registered charity. Made up of both corporate and individual memberships from 80 countries, members include the sectors and disciplines of textiles, clothing and footwear. The aim of the Institute is to facilitate learning, disseminate information and recognise achievement.

Gordon Fraser, the Senior TDL Technician, joined the AUT during 2007. Gordon has over 30 years of industry-based technical knitting experience both within the United Kingdom and New Zealand. Before moving to New

Zealand Gordon worked as a knit technician for Scottish fashion label Pringle (TDL website, 2016).

I first visited the lab during 2007 not long after its setup, and have since attended a number of symposiums and digital textile print workshops hosted by the TDL. I am therefore familiar with the laboratory and have a clear vision of how the staff can offer expertise to support my MDE project through knit sampling and onto possibly small-scale production. In preparation for my MDE 404 work placement, I met with Peter and Gordon to discuss my project to date and to determine how best to engage with the TDL knit facilities and capabilities.

From this first meeting Gordon identified that the project would push the limits of the technologies available at TDL and he indicated that the programming would be challenging for him. He suggested we work towards creating a functioning 'X' system both front and back within a knitted garment, as the additional placement of the chest band and varied back strapping arrangement would be extremely complex to both programme and to knit.

Fabrication

Occasionally during the wearing of the Lycra® toiles Ben had indicated he was feeling a bit hot. This is not an uncommon response to the wearing of Lycra®, especially next to the skin. The Lycra® used for toiling was sourced from Bendon NZ. Although it is commercially used in undergarments, the torso surface area my design covered was much larger than the average size of underwear Bendon produces. In response, my personal experience in the wearing of merino wool base layer garments (commercially produced by world recognised New Zealand label Icebreaker) and my fibres and textiles knowledge, superfine merino wool was selected to knit the next pressure garment toiles at the TDL.

Merino wool is recognised within the fashion industry for its abrasion resistance, good elastic recovery and resilience qualities when made up into garments. Merino is lightweight and has a soft handle, plus the ability to absorb moisture and wick (draw away) from the wearer's skin (Baugh, 2011, Humphries, 2004). Within industry the wool's quality is related to its fineness and breed of sheep. Wool is given a micron count and the fashion market most commonly includes 20.5 - 17.5 micron-rated wools within garments (DEA Yarn, 2016). The lower the micron figure, the finer the wool. Fine wools have shorter fibres, finer crimp (bends in the fibre) and are a smaller diameter. High quality fashion yarn is usually worsted (combed) which removes shorter fibres and arranges remaining long fibres more or less parallel to each other resulting in a smoother surface (Humphries, 2004).

Spandex yarn is able to be knitted with a merino yarn which will provide additional elasticity and structure to the pressure garments. Gordon supplied contact details for Levin-based yarn wholesaler DEA Yarns. I made contact with them in consultation with Gordon, resulting in an order for 20.5 micron merino wool and an ultra-fine quality elastic/spandex yarn. Cordall, another industry provider, was approached to source heavier duty elastic. This company manufactures cord and elastic and supply a variety of cords, elastics, tapes, fashion elastic cord and even bungy cord to customers within New Zealand and internationally. Cordall elastic sales representative Janet recommended I trial their 50mm width heavy duty elastic within my garment. This was double the width of the elastic included in the Lycra® prototype garments.

Understanding machine knitting technology

Before attending my MDE 404 industry work placement at the TDL, background knowledge was required to better understand the digital age of machine knitting technology. Therefore, a review of the basic fundamentals of machine knitting methods was undertaken with a particular focus on weft knitting technology and processes and the CAD system compatible with the TDL's Shima Seiki SEG-SWG WholeGarment® machine. Two texts were of particular value - Wonseok Choi and Nancy Powell's 2005 Journal of Textile and Apparel, Technology and Management (JTATM) published paper which discusses *Three Dimensional Seamless Garment Knitting on V-bed Flat Knitting Machines*, alongside Jenny Underwoods' 2009 project *The Design of 3D Shape Knitted Preforms* submitted for her degree of Doctor of Philosophy RMIT University.

Weft knitting has a long history with industrial manufacturing. It takes its name from the direction which the yarn feeds to the needles from the side so that loops form across the fabric side-by-side, as opposed to warp knitting that feeds to the needles from the end, forming loops that snake their way up the fabric (Humphries, 2004).

Industrial flat-bed knitting machines allow for a fully automated computer controlled method of production. The key components and mechanisms of an industrial knitting machine include the needle, needle bed, racking mechanism, carriage and cams, yarn carriers, takedown, yarn threading mechanism, sinkers and stitch presser. Knitting machine needles consist of a number of parts - the latch, hook, closing element and butt. Loops are formed on the needle. As the needle raises, the latch opens and receives the yarn forming a loop which is enclosed by the closing element and latch as the needle lowers. As the needle rises again the loop is released and a new one formed. Within flat-bed machines needles are arranged along horizontal beds. Two needle beds placed at right angles form an inverted 'V' shape also known as a v-bed and four needle beds form an x-bed (Choi & Powell, 2005, Underwood,2009).

Thin metal plates called sinkers sit at right angles between adjoining needle beds. They assist the stitch formation by holding down old stitches as new ones are formed enabling a tight and uniform knit structure to be formed. Also when knitting is programmed onto selected needles, sinkers hold the non-selected needles out of the way ensuring there is no interference in the knitting. The stitch presser is another method of controlling stitch formation. The presser holds stitches while knitting occurs on selected needles. The length of the needle bed determines the maximum width of fabric. Industrial needle beds are made up of over 200 needles and the distance between each needle determines the gauge of the machine with the number of needles per inch equalling the gauge (Underwood, 2009).

Figure 19 Industrial flat-bed knitting machine

The racking mechanism on a flat-bed allows for the transferring of stitches over a number of needles to the left or right. The carriage, consisting of cam, cam plates and yarn feeders, passes over the needle beds. Cams control the movement of the needles. As the needle butts pass through the cam channels, needles are independently raised and lowered forming sequential stitches. Cams are fixed to a cam plate and there are both front and rear cam plates which are connected by a bow. Knitting machines normally have between two and four cam systems and setting of the position of the cams enables the length of the stitch to be determined (Underwood, 2009).

The yarn carriers (or feeders) also travel with the carriage and feed from the tension device to the needles. Yarn must be taut when it contacts the needles. The takedown mechanism is made up of combs and rollers which remove the knitted fabric away from the machine at a constant speed and tension. This tension helps form a new stitch as the old stitch drops off and the new stitch contacts the hook.

Weft knits are derived from three primary knit stitches - plain, purl and rib. Variations of these stitches in the knitting process can produce vast fabric structures. Plain fabric, the simplest construction of weft knitted fabric, is also often referred to as single knit or single jersey. It is produced on a single needle bed. As the yarn is feed across the needle bed the needles draw a new stitch through the last stitch before it is released. Plain fabric stitches are drawn from the back to the front, or face, of the knitted fabric. Plain fabric, although uniform, is not that stable and can distort easily compared to other knitted fabrics. Also, if yarn is not secured correctly or snaps it has a tendency to ladder or run.

When stitches are drawn in the opposite direction from front to back a purl stitch is formed. Purl fabric has loops formed on both the face and back. It is knitted on two needle bed and stitches are transferred back and forth between needles. Rib fabric is produced on two needle beds. Stitches alternate from front and back and are formed in opposite directions resulting in the face and back of the fabric looking identical. Rib is a balanced fabric with good elasticity in the course direction (Underwood, 2009).

Tubular fabric is an extension of plain knitting, where two needle beds are used but there is no transferred between them. When knitting open-ended tubes with finished edges, WholeGarment® technology is required as the two additional needle beds store the stitches independently as the front and back beds cast off separately.

The knitting machine industry dates back to the 16th century when flat-bed knitting frames were invented to create hosiery. Following this early development, a number of knitting machines were progressively developed to stitch large panels of fabric that were then cut, sewn or linked into complete garments (Underwood,2009).

The fully-fashioned process followed, whereby separate shaped garment parts are programmed to knit to shape through the increasing and decreasing of individual stitches. This technology eliminates cutting but still requires the post knit process of sewing or linking of garment pieces into a whole.

More recently during the 1990s, Japanese manufacturer Shima Seiki introduced Whole Garment ® knit technology radically automating the production of machined knitwear. Sophisticated computerised production enables the completion of whole garments via a tubular knit technique where shaped body and sleeves can be knitted at the same time. One entire piece is knitted three-dimensionally on the machine, totally eliminating the cutting and sewing process. This seamless technology provides a number of benefits including less intensive labour needs, less waste in the manufacturing process, shaped products/garments that can be uniquely designed for limited production, niche markets and offering one-off made-to-measure desirable outcomes which fit well with the increasing appreciation of 'slow fashion' (Choi & Powell, 2005, Underwood,2009).

Consistently, whole garment knitwear is promoted as producing better fit and comfort as compared to traditional fully-fashioned knitwear that often has the addition of seamed shoulders, underarm points and necklines. Knit designers are better able to refine structures and shapes for production when utilising computerised Whole Garment® programmable technology.

Applications of complete garment knitting remains primary based within the apparel industry, however, over recent years the extension into areas such as fashion accessories, automotive interiors, upholstery and medical textiles has developed. Seamless tubular knitted structures such as knitted orthopaedic supports, medical bandages and compression stockings are now commonplace healthcare products, all of which include specific performance and aesthetic requirement considerations during design and development (Choi & Powell, 2005).

Knit production system

The Shima Seiki SDS-ONE® Design System is an integrated knit production system including design preparation, design programming, design processing and knitting. This cohesive process as operated in the TDL enables the use of a knitting machine as a design tool rather than being limited to just the manufacturing process of knitting a garment or product.

The initial planning and development of the knit ideas includes the inputting of the proposed design into the knit CAD system. Within this system there are several programmes which individually relate to various aspects of the knit production. The most commonly used are Knit-paint and Knit-design. The Knit-paint program is designed as the platform where all technical knit data inputted by a technician is constructed, processed and checked through simulation on screen. The Knit-design program is for design work of 2D surface stitch structures, yarn and colour selection which can be virtually sampled on screen either through drawing on the existing database library of knit structure patterns or virtual creation of unique knit structures from scratch using the software. Knit-design permits quick realistic estimations of the proposed knit structures without the need for sample knitting. This program also provides the opportunity to identify and resolve knit problems on screen (Choi & Powell, 2005, Underwood,2009).

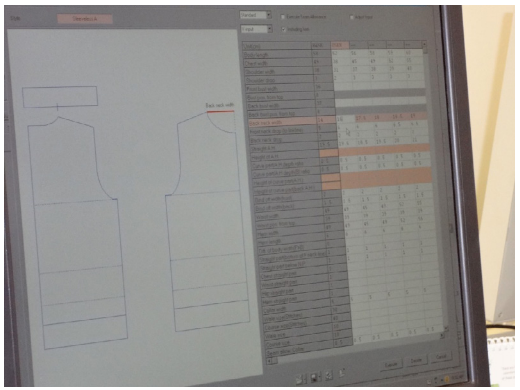

Figure 20 Knit CAD system

The apparent ease of designing through this system can cause problems if the operator does not have a sound understanding of the capabilities of the knitting machine. A designer's highly complex concept sketch can often be reasonably easy to create virtually on screen with this software, but in reality could be impossible to knit. Consequently, the operating CAD programmer or technician needs to have a good technical knowledge and understanding of the parameters of what is possible to knit on an industrial machine to successfully undertake the initial data input.

Programming the design involves converting the design to programme language. This takes place through Knit-paint, the least automatic of the programmes. Three parts of the input data must be set - the structure pattern, the option lines and the pattern development assignment. The structure pattern design area is set through the stitch code colour/number list where each different stitch type or movement of a stitch is individually represented by a coloured square and number. Option lines are then set informing the knitting machine how the design is to be knitted. Each line represents a different part of the knitting process, for example, the selection of yarn carriers. Option lines provide some flexibility in the knit program as their inputted data can be changed at both the processing and knitting stage. Setting the pattern development assignment provides information about the width and placement of the programmed knitting on the knitting machine (Underwood, 2009).

Design processing involves processing and saving the design to a formatted digital storage unit or network allowing the knit program to be read by the knitting machine. Knit parameters based on the option lines are set and the machine type the program will be knitted on is specified. During processing faults in the knit program are detected and highlighted allowing them to be addressed prior to the machine beginning to knit. The Knit-paint program also allows digital control simulation of the knitting process enabling even more in-depth pre-knit checking. Once design processing is complete, the knit program is transferred to the knitting machine via pen-drive. Knitting begins once the knitting machine is set up. Yarn is selected and threaded through the tension devices to the yarn carrier. The knit program is selected, read and the knit parameters set. The knit program is then knitted (Underwood,2009).

A further extension of basic programming is through the use of Package Software, which uses a system of colours (and numbers) that each represent a combination of stitches or 'package'. Complex design outcomes are built and communicated in a 2D format on screen. Package developed by Shima Seiki is split into three components - the package base pattern, the compressed pattern/drawing and the development pattern/expanded drawing.

1. Base patterns

Package base patterns are the individual knit programmes made up of small blocks of stitches represented by a system of registered colours and numbers.

2. Compressed pattern/drawing

The compressed pattern or drawing is the overall structure of the knit program. It is a simplified version of the base pattern packages/drawings. At this stage of programming the compressed pattern can be altered but the package base patterns will remain unchanged. This feature is helpful when complex knit designs are being developed.

3. Developed pattern

During the developed pattern stage the compressed pattern/drawing is expanded to form the development pattern or expanded drawing. During this automatic digital process of 'expanding' the base patterns and compressed drawings are combined together. Each registered colour is read from the compressed pattern/drawing and its corresponding base pattern is inserted into the compressed pattern/drawing (Underwood, 2009).

Package Software is particularly suited to the apparel industry. Rather than having to focus on establishing an entire knit program from scratch, a knit technician can build onto and alter existing knit pattern files from the programs library. The advancements of WholeGarment® knitting is a consequence of the advances in both digital knit programming and industrial knitting machine technology (Choi & Powell, 2005, Underwood, 2009).

TDL work placement

My first placement at the TDL involved three days working with senior knit technician Gordon. The main purpose of this initial lab placement was to test and document two key features of the proposed knitted compression garment. It was agreed, through the use of the digital knit technology as a design tool, that existing prototypes were to be replicated. Replacing commercially manufactured knitted Lycra® fabric, firstly with a purpose knitted structure fabricated from 20.5 micron merino wool and ultra-fine elastic yarns. Secondly, experimentation as to whether it is possible to machine knit singlet-shaped garments with an internal 'X' shaped tubular system both front and back. This knitted tubular structure will need to be capable of containing an elasticated 'pull' system which can be activated by the wearer.

- The question is as follows: Is it possible to knit, using the TDL's Shima Seiki WholeGarment® SES-SWG, a close-fitting singlet-shaped undergarment, panelled with a mix of fine wool and elastic yarn, that is stable enough to support a tubular structure, which contains pull-able 'stretchy' drawstrings?

Engaging with both new technology and materials for design of the proposed pressure emitting garments was somewhat daunting, even after gaining some background knowledge on the TDL's Shima Seiki design system. I very much appreciated the highly complex technical nature of the programming requirements I was asking Gordon to perform. We began by producing single jersey structured knit tension swatches to test the quality of the selected merino yarn and to achieve the correct tension when knitting. We then compared the knit structures pre and post steaming. Accessing the software library of garment production templates, a standard size 12 boy's singlet-shape was selected and knitted in merino wool yarn as separate front and back panels.

After the trial, singlet-shaped garment fronts and backs were test knitted, the ultra-elastic/spandex yarn was introduced and merino wool yarn and ultra-elastic ends were knitted together into tension swatches. Once steamed, the swatches were pinned in strategic points onto a stand to test the stretch of the knit. We found that the ultra-elastic retracted further than the wool. This resulted in a puckered knit surface on both the face and the back of the sample when at rest. However, the fabric did have more stretch after steaming. A rectangular shaped swatch with inclusive shaped side panels of wool and elastic were then programmed and knitted. This replicated the shaped side panels included in the Lycra® toiles.
Once the basic singlet shaping, stitch tension and yarn combinations were effective, it was time to experiment with programming into the singlet panels internal tubular 'X' shaped structures through which the elasticated strapping will track.

CAD Software

This design request proved to be quite a technical challenge for Gordon as it was pushing the parameters of what is feasible to knit. Tubes and tubular joint connections such as an 'X' shape require very skilled technical abilities to build using Package Software. Informed by his experienced understanding of possible issues associated with operating an industrial knitting machine, Gordon suggested firstly working towards achieving the sought-after combination of single knit and the tubular structures in a rectangle knit panel. Then, once that combination was effective, the next stage was to introduce the shaping of the singlet form including the neck and armhole shaping.

Figure 21 Gordon steaming knit sample

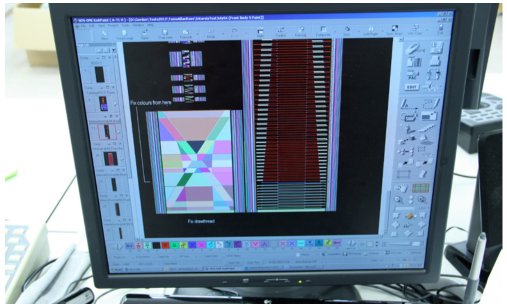

Figure 22 Shima Seiki design system

At the end of my third day working with Gordon he managed to achieve the result of two faultlessly knitted rectangular panels inclusive of functioning 'X' shaped tubular structures with internal shaped merino/elastic panels at each side. Gordon referred to his achievement as Saltire, the Scottish flag.

Figure 23 Knitted panels including crossover tubes

At this time Gordon informed me it was not going to be possible to knit the singlet-shaped garment as a whole garment using the method of feeding the merino and elastic yarns separately. Due to the complexity of this garment design, each individual front or back panel had required all needles to be working and therefore there was no opportunity for further full-fashion shaping within the functioning of the Shima Seiki WholeGarment® SES-SWG. Placement of the opening ends of the tubes had to be positioned at the bottom of each panel rather than at hip level on the sides as originally designed. All nine feeders were working to knit the 'X' structure and shaped panels, four carrying merino and elastic ends, five carrying just merino ends.

Gordon suggested I look into sourcing a yarn spun with a mix of merino and elastic to remedy this issue. We thought it would also be interesting to trial a blended yarn (Merino/Elastane) to investigate whether it would improve the puckered stitch surface. This would serve as a comparison to running merino wool yarn and ultra-elastic ends through feeders together, resulting in

Figure 24 Gordon threading Whole Garment knitting machine

the problem of the two different yarns feeding at different rates. The knitting technique of plating is also an option to consider which may reduce the puckering on the surface. Plating knits two different yarns, one behind the other, creating a fabric that appears lined and, in this instance, the merino could be lined with the ultra-elastic. The TDL did not currently have the additional fittings required for plating on the Shima Seiki WholeGarment® SES-SWG machine but Gordon would look into the feasibility of adding this feature to the TDL machine.

Trialling knitted panels

Toile 6 user trial

On return to Dunedin a toile was constructed from the two rectangular panels. The 50mm elastic was threaded through the tubes and stitched down through all layers with an industrial plain sewer straight stitch at the shoulders. The top of the panels was left hanging in a cowl shape to enable pulling over Ben's head. At the sides, a gap the width of an armhole was left and the side seam was also stitched with the plain sewer down to the bottom of the panels where the elastic straps protruded. Unexpectedly this rough prototype fitted Ben reasonably well. The placement of the 'X' both front and back was comfortable for him and the wider elastic had good coverage across his mid-back and chest. Ben commented he could "feel the pulling better" and pointed to his shoulders. The irregular thicknesses in the seaming caused Ben some discomfort, so he preferred to wear it inside out.

Figure 25 & 26 Tolie 6 Front and Back

Intarsia machine

Before I had success locating a suitable micron merino/elastane blend yarn, Gordon informed me that the TDL had purchased a Shima Seiki SIG 122 Intarsia electronic knitting machine and it may well knit my pressure singlet design effectively. Intarsia is a knitting technique predominantly used to incorporate inlays that are patterned or coloured differently from the background knit structure/colour. Intricate designs can be knitted without float yarns across the reverse side of the knitted panel. Consequently, complex knitted panels are lighter weight. Another exciting feature of this machine is the capability to knit circuitry for electronic textiles which include conductive yarns (TDL, 2016).

Figure 27 Sample knitted on Intarsia machine

During my next visit to the TDL, Gordon and I began as we did on the Shima Seiki WholeGarment® SES-SWG by creating single jersey structured knit tension swatches, this time knitted on the new Shima Seiki SIG 122 Intarsia machine. Pleasingly, the machine performed well as there was reduced puckering on the surface of the knit structures, both pre and post-steaming.

Toile 7 user trial

Following observations during the wear testing of the previous toile knitted on the WholeGarment® machine, inclusion of ribbed bands on the hem of the garment was added to the garment design. This reduced the issue of the garment 'riding-up' on the body during wear. The rib knit structure was also sample tested on the Intarsia machine prior to Gordon altering the CAD specifications in preparation to knit test a full size panel. Once the tubular 'X' was knitting correctly, Gordon added the rib band to the hem of the panel and positioned the exit for the elastic straps at hip level. Achievable on the Intarsia machine owing to its 21 carriers, it was also possible to shape the armholes. However the shaping of a neckline was not possible. Gordon recommended attaching an individually knitted rib band during the construction of the garment to form the desired neckline finish. After spending another two days with Gordon at the TDL, I felt pleased that the new Intarsia machine had resolved a number of the issues identified initially. It successfully converted the concept of the pressure garment from Lycra® fabrication to the specialised domain of computer aided industrial machine knitting.

The garment

The features of the garment as it is presently are:

- The vest includes the knitted tubular 'X' shaped pressure delivery system both front and back.
- The two 'X' join together at the shoulder seams of the garment.
- The bottoms of both 'X' protrude out of the side seam at the wearer's hip level.
- Forming the pressure delivery system, two 50mm industrial strength elastic straps run through the knitted tubular 'X', up one side of the wearer's body, across one shoulder and down the other side of the body.
- Strapping crosses each other at the centre cross over point in both the front and back 'X'.
- Both elastic straps hang from the hip level exit opening points and the top and bottom of each strap are joined (machine stitched together) on the outer of the garment to form the pull handles.
- Internally the garment structure includes shaped side panels that are knitted blending both the superfine merino wool and elastane fibres.
- Ribbing detail is knitted into the hem of the garment with the dual purpose of providing a more contemporary aesthetic and reducing the effect of the garment 'riding-up' the wearer's torso.
- The fully-fashioned armhole shaping is achieved on the Shima Seiki SIG 122 Intarsia machine, however, due to maximising the capability of the machine, the neck shaping detail has been achieved through a separate industry construction procedure by applying a cotton rib band to shape and finish the garment neckline.

Figure 28 Toile 7 front

 

Figure 29 Toile 7 side & 30 Toile 7 back

Over recent months, the garment has been graded (resized). I sent Gordon a paper pattern including measurements and placement of style details such as the 'X', width, the shaping for the side panels and placement of rib band. I have continued to make up the individual garments, however, now that the garment design is knitting successfully on the Intarsia machine, I plan to move towards building a relationship with a local knitwear factory, Otago Knitwear, to investigate having the seams 'linked' and separately knitted ribbed bands for the neck finishing applied professionally.

Looking Forward

Industry Shima Seiki operators

Looking forward to considering production capabilities within the New Zealand knitwear industry, two knitwear manufacturers are highlighted, Otago Knitwear and Weft Knitting Company Limited. Dunedin-based knitwear manufacturer Otago Knitwear produces a number of knitted products including school uniform jerseys and vests, club and corporate knitwear knitted accessories, alongside a number of in-house fashion labels including Silver Stream, Felicity and Xquisite. Otago Knitwear offers on-site design, knitted fabric and garment construction services.

Otago Knitwear operates Shima Seiki computerised knitting machinery, including an Intarsia machine. Gordon reports he has in the past worked with their knit technicians training on the Shima Seiki WholeGarment® technology. Now that my pressure garment is to an industry standard ready for manufacture it could well be knitted and constructed locally by Otago Knitwear Limited.

The other South Island-based knitwear producer, Weft Knitting Company Limited situated in Christchurch, specialises in the design and manufacture of thermal wear and retail knitwear lines. They have a business focus of supporting markets within New Zealand as well as internationally. Weft Knitting Co. Ltd has also invested in WholeGarment® technology on which they knit thermal wear in both synthetic and merino wool yarn. The design and manufacture of knitted thermal wear is of particular interest to this project as thermal wear is predominantly designed and knitted to be worn as close fitting undergarments which hug the body's form.

Conclusion

Reflecting on methodology

The dual methodology approach of this study incorporating a case study informing the functional clothing design process fitted well as the development and trialling of the contemporary therapeutic garment 'intervention' was evaluated and progressed. Yin (2003), notes case studies have a distinctive place if evaluative research is undertaken within a real-life context. Ben's case enabled the study of his response to the trial wearing of each toile within his regular and familiar environments and information gained (insights) informed the steps of the designing process.

Problems (findings) encountered during the trialling were able to be evaluated and revisited as the circuitous design path often resulted in backtracking to review different literature and the take-up of varied design development directions. As expected when engaged in a design process, there were a number of findings that were resolved, for example, inclusion of more fitted elasticated side panels with in the garment resulting in the vest becoming more structured and stable during wear. Additional problematic findings often develop alongside resolved issues, in this case the puckering on the surface of the garment. This knock-on effect further informed the problem range when working towards making the garment design more responsive to the Ben's needs. Researchers in the fields of clothing and textile design, such as Lamb & Kallal (1988) and Watkins & Dunne, (2015) highlight within their individual clothing design methods that any conflicts between wearer needs often result in the application of a number of modifications of a prototype. These need to be worked through the process before final production can be implemented.

Further research & market opportunities

This initial study has helped establish what Ben will tolerate when given the opportunity to self-modulate the sensation of pressure through wearing the knitted garment. Working towards solving the lack of functional, appealing and inclusive clothing that addresses deep pressure stimulation input from garments, initially identified for my family member, I have come to realise this problem is much larger than just my family member.

It is now predicted this garment design could allow a number of wearers to personally modify sensation, specifically the experience of deep pressure in order to assist the wearer's integration of tactile and proprioceptive sensations. This in turn could lead to the 'normalising' of behaviour through reduction in symptoms, which helps facilitate improvements in daily life functioning and well-being.

In comparison to this study, which has been predominantly driven by product development, I see this long term experimental research project clearly being informed by a number of possible end users of varied ages. I look forward to the next stage of the project, including multiple participants within case studies, informed by the functional clothing design process that will most likely focus on the question:

- Does this wearable pressure delivery system meet the needs of a range of users?

I understand on-going garment design modification will need to be addressed as this garment is tested more widely. The process of evaluation of each wearer's individual case is foreseen to continue to drive innovation, as it has during this initial single participant study and this can only result in a more robust product.

Safety variables such as measuring of wearer vital signs and the establishing of user protocols will need to be examined in more depth as this garment design is progressed and tested further. The 'on and off' schedule, currently a typical manufacture recommendation for compression garment wear (www.squeasewear.com), is addressed within this current design through the wearer controlled pressure delivery system. It is thought highly likely that the majority of wearers will embrace the pull and release quality of the garment. Pull strap lengths have been considered to prevent entanglement, having said this, it will be of particular interest to observe how other wearers interact with the garment.

The extent and groupings of the possible end-users is somewhat unknown, but once in existence as wearable functioning garments, my hope for this therapeutic device is that it is likely to create its own demand and market. As my research to date indicates a diverse range of users including those effected by ASD, developmental disorders and a number of mental health related experiences, such as anxiety, many user groups are likely to benefit from the calming effects of wearable self-controlled deep pressure.

Appendices

Todd Foundation Award

During 2012 I was granted a Todd Foundation Award for Excellence (ITP Sector). This enabled me to access the consultancy and industrial machine knitting facilities of the TDL for my MDE 404 work placement.

The Todd Foundation established in 1972 is a private family philanthropy based in Wellington, Aotearoa New Zealand. This foundation provides funding to New Zealand organisations that contribute towards the Todd Foundation vision of *'Inclusive communities where families, children and young people can thrive and contribute.'* Funding is directed throughout New Zealand communities by means of a number of identified priorities.

Generously the foundation has made one of their award priorities available to Polytechnic students studying at Level 7 or above who wish to undertake a research project - The Todd Foundation Award for Excellence (ITP Sector). These scholarships are offered annually in four categories: Science and Technology (including Agriculture and Conservation), Business and Commerce; and Health, Engineering and Manufacturing (including Architecture and Design) and Social Sciences (Todd Foundation website, 2013).

During the 2012 round I applied under the categories Business and Commerce; and Health, plus Engineering and Manufacturing (including Architecture and Design) stating that as part of my initial MDE studies I had identified my applied research-driven project as sitting well within the industry educational collaborative environment of the TDL. I noted that the TDL knit technologies, including a computer-aided design system and whole garment knitting machinery, are appropriate pre-production prototyping technologies with which to test, evaluate and develop effective pressure emitting fabrication, systems and garments to address SID.

I was successfully granted NZ$6,000 for my research project, *Design of therapeutic compression garments: informed by sensory integration dysfunction*, specifically to undertake a MDE 404 industry placement on site at the TDL. My proposed budget outlined that I would use the award funds to contribute towards the knit technician's R & D consultancy fee of $115.00 per hour, also fabrication costs for yarn and notions to be used during the prototyping stage of the project.

Industry placement summary (From Gordon)

Tania's Project
The programming of Tania's garment proved to be quite a challenge. The main reason for this was the Tubular X shape which crossed the panel. The use of this structure meant that the program could not be constructed using automatic software; instead a programming technique known as "package" was employed.

The panel design incorporated areas of high stretch with areas of normal stretch; the best way of achieving this was to knit the panel as an intarsia. Some areas of the panel used up to 8 yarn carriers per knitted row; some carriers were threaded up with merino yarn while the remainder were threaded up with a mixture of merino and elastane.

The machine used to knit this garment is a specialised intarsia knitted machine manufactured in Japan by Shima Seiki. This machine is fitted with 30 yarn carriers, and it is 14 gauge. It did take a number of attempts knitting this panel before the panel was knitted to an acceptable state. There are a number of reasons for this, notably program errors, feeder parking positions and threading the yarn feeder with both types of yarn (this provided a particular challenge as the elastane and merino would feed at different rates).

Attached a few diagrams. These should illustrate the programming and knitting process.

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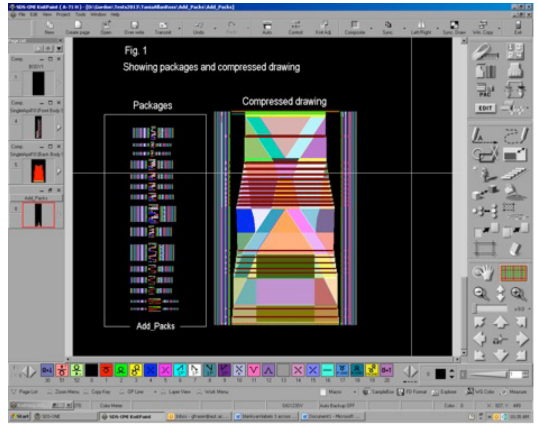
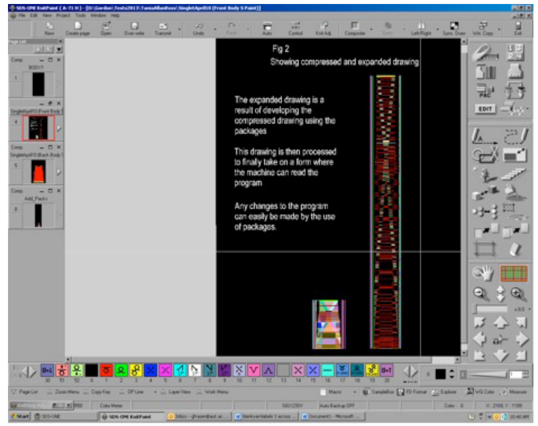
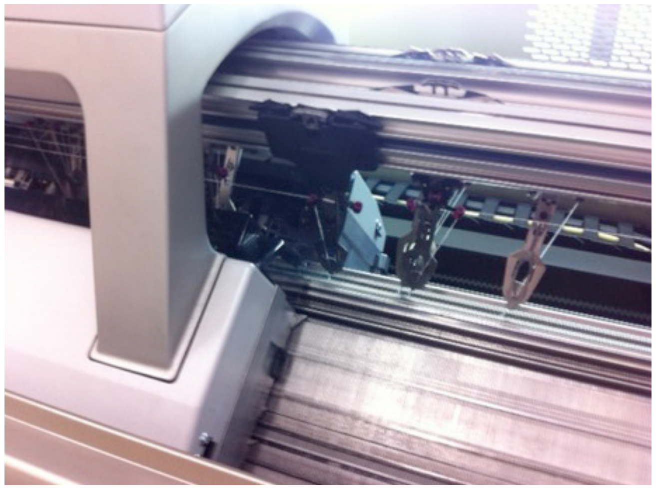





The knitting machine used to knit this garment.


Yarn stand showing the yarn cones used to knit this garment.


The carriage and yarn feeders.


The finished panel as it came off the machine.

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Glossary

Adaptive response: "An appropriate action to an environmental demand. Adaptive responses require good sensory integration, and they also further the sensory integrative process" (Ayres, 1979,p.181).

Modulation: The brains ability to regulate and organise the degree, intensity, and nature of the individual's response to sensory input in a graded and adaptive manner.

Occupational profile: Information gathered through formal and informal interviews with the client and key stakeholders that describes the client's "occupational history and experiences, patterns of daily living, interests, values, and needs" (American Occupational Therapy Association (AOTA), 2014, p.S13). The occupational profile provides data that allow the evaluator to gain an understanding of the child and the family and identify their concerns and are used to determine how performance is affected by these concerns (AOTA, 2014; Smith Roley, 2006)

Outcome: The effect, consequence, or result of an intervention (Melnyk & Morrison-Beedy, 2012).

Outcome measure: Evaluation of the results of an intervention (Melnyk & Morrison-Beedy, 2012).

Proprioceptive system: From the Latin word for "one's own", proprioception is the sensation arising from the muscles, joints, and tendons. Proprioceptive sensations provide information about the length, position, and tension of muscles and joints; also known as position sense (Gardner, Martin, & Jessell, 2000).

Sensory integration: The organization of sensation for use (Ayres, 2011); a theory and frame of reference that describes how the nervous system integrates sensory information for use in adaptive behaviour (Smith Roley, Blanche, & Schaaf, 2001; Smith Roley & Schaaf, 2006).

Tactile defensiveness: A specific type of sensory integrative dysfunction in which tactile sensations cause excessive emotional reactions, hyperactivity, or other behavioural problems (Ayres, 1979).

Tactile system: The sense of touch; sensation of touch arising from the skin (Ayres 1997).

Vestibular system: Sensory system that is responsible for maintaining balance, posture, and the body's orientation in space. It also controls reflex eye movements to stabilize images on the retina despite motions of the head. The vestibular system consists of receptors in the semicircular canals of the inner ear, the utricle and saccule, which receive input that is conveyed through the vestibular portion of the vestibulocochlear nerve to the central nervous system structures that interpret and respond to the information obtained (Golberg & Hudspeth, 2000).

Taken directly from: Schaaf, R., C. & Mailloux, Z. (2015). Clinician's Guide For Implementing Ayres Sensory Integration: Promoting Participation for Children With Autism. USA: The American Occupational Therapy Association Press.

Bio

Figure 31 Author

Tania Allan Ross is a senior lecturer in the School of Design at Otago Polytechnic. She is the parent of a child with sensory differences, the combination of this experience and an interest in the design of user-centred garments has led her to investigate the development of garments that apply pressure.