Smart Tack:

A textile-based system for the monitoring of equine physiology

Hollee Fisher | Master of Creative Technologies (MCT) | 2016

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A thesis submitted to Auckland University of Technology in fulfilment of the requirements for the degree of Master of Creative Technologies.

2016

Design and Creative Technologies

ABSTRACT

Smart textiles are extending the traditional functionality of textiles and making a significant impact within the medical and healthcare industries. However, the field of animal care has been slow to adopt the use of smart textiles. This research explores the use of this emerging technology within the field of animal care. A research through design approach has been used to utilise both theoretical and practical investigations to explore possibilities for the use of smart textile applications in the equine industry. A combination of knowledge in textile design and technology, aids in the creation of 'soft' textile electrodes through the construction of composite and conductive fabrics where textile structures, material properties and yarns are explored for their technical performance. The practice-based research results in the construction of a prototyped smart textile system for continuous monitoring of equine physiology.

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ATTESTATION OF AUTHORSHIP

"I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning."

Hollee Fisher

7 . 06 . 2016

ACKNOWLEDGEMENTS

I would first like to thank my primary supervisor, Dr Mandy Smith for your continuous encouragement, advice and unwavering support.

Dr Frances Joseph for your support and guidance throughout this project.

My sincere thanks to Peter Heslop at AUT's Textile and Design Lab, and in particular Gordon Fraser for your patience, knowledge and support. Yasir Al-Hilali and the AUT Engineering Department for their generous time, advice and assistance. Liz Ward, Waikato Stud and all the veterinarians who assisted me in the development and analysis phase of the project, thank you, without your support this project would have not been possible.

I would like to gratefully acknowledge the Auckland University of Technology Ethics Committee (AUTEC) and the University of Auckland Animal Ethics Committee (AEC) in particular Dr Eddie Dixon for his invaluable time and help. Thank you to Desna Jury, Faculty of Design and Creative Technologies and the Master of Creative Technologies Scholarship for the role you have played in supporting my research.

Lastly I would like to thank my family and friends for their loving support, encouragement and understanding.

ETHICS APPROVAL

Auckland University of Technology Ethics Committee (AUTEC)

Ethics application reference: 15/292

Ethics Approval Period: August 25, 2015 to August 24, 2018

University of Auckland Animal Ethics Committee (AEC)

Ethics application reference: 001729

Ethics Approval Period: April 6, 2016 to April 6, 2019

INTRODUCTION

INTRODUCTION

Smart textiles are making a huge impact within the medical and healthcare industry, however the integration of this technology into animal care has not yet been widely adopted (Ajami & Teimouri, 2015). Textiles are most commonly associated with apparel and home or commercial furnishings but their application and contribution within medical and healthcare is increasing. The technical textile market is one of the fastest growing sectors of the industry (Cools, Morent & De Geyter, 2015). With current developments and innovations occurring within fibre and textile technology, new opportunities are being realised and relationships between textiles and the body are changing. Textiles are now transforming into sensing materials that have the ability to monitor physiological responses. This project focuses on the translation of current applications for the human body into a potential monitoring device for use within the equine industry.

This research provides a formative body of knowledge for a specific application in the arena of smart textile development, while also contributing to the wider field in terms of more generalisable technical understandings. It endeavors to overcome some of the complications associated with smart textiles through the development of a smart textile-based system for monitoring equine physiology. A research through design approach (Frayling, 1993) to this investigation explores the construction of textile sensors and their surrounding base fabric, particularly, in relation to knitted stitch structures and yarn composition. The link between textile techniques such as knitting and felting are also explored as an integral element of design and sensor integration. An interdisciplinary electronic element to this project utilised textile design to help expand the possibilities of electronic integration and explore new ways of thinking about sensor surfaces and their structural relationships and behavior within an applied product development project.

The prototype developed in response to this research is based around the manipulation of current designs in equine tack. An investigation into the integration of ‘soft’ textile-based electrodes within this prototype adopted the use of conductive yarn as an alternative to traditional ‘hard’ electrodes. The prototype is targeted at equine veterinarians with research resulting in a working prototype that has the ability to demonstrate the monitoring of equine heart rate via a textile-based electrocardiogram.

Chapter one offers a background narrative that positions the context of this research by identifying the latest developments within sensing technology and their links to textiles and to human and animal care.

Chapter two discusses the nature of research through design and conceptualises the use of underlying methodological issues and a mixed methods approach to this research project. Chapter three describes and reflects on the design practice and findings, outlining how this project developed, and through the process of textile design, explores the integration of sensing and monitoring technology into the prototype 'Tech Tack'. The final chapter concludes and presents a summary of the research and its contributions prior to discussing future pathways for further development.

Rationale

As a textile designer, my interest lies both within textile innovation and medical care applications which, during this project, expanded into the field of veterinary care. These contrasting interests motivate my research to explore a middle ground between these two diverse disciplines. The variety of textile structures offer unique solutions to some of the current challenges of electronic integration into health care products. Advances in new fibre-based materials and production techniques offer enormous potential to develop new textile structures and fabric properties not traditionally associated with applications or products within the areas of equine health care (Rivero, Urrutia, Goicoechea, & Arregui, 2015).

There have been significant advancements within the healthcare industry in relation to the introduction of smart textile and technological innovations such as the development of nanotechnologies and intelligent systems (Agarwal & Agarwal, 2011). However an initial literature review and consultation with experts identified a gap with little information focusing on animal care and links to smart textiles. This opened up the opportunity for advancements and new innovations within the equine care sector by introducing the use of smart textiles into product applications. This research expands on current uses of smart fabrics and explores potential application benefits for the equine industry.

The New Zealand equine industry can be classed as multi-disciplined comprising of a range of sectors including, exports, racing and wagering, recreational interests and various levels of sport. The 2012-2013 season saw 1511 New Zealand Thoroughbreds exported with an estimated export value of $130 million (New Zealand Thoroughbred Breeders' Association, n.d.). With a strong established international export market, New Zealand is internationally recognised for producing sound and durable racehorses. An engaged interest by equine veterinarians into how smart textiles could enhance the wellbeing and recovery of horses has been ascertained through this project. With the equine industry being a significant contributor to the New Zealand economy a smart textile applications in the area of equine health care would be of huge benefit. This research helps promote new advancements in this area.

Research Objectives

This research examines the extent to which textile design can be used to develop a smart textile system for the monitoring of physiology while implementing this technology into an equine-based product. It addresses the question: Can smart textiles be implemented into equine care through the development of a smart textile system?

CONTEXTUAL FRAMEWORK

1. CONTEXTUAL FRAMEWORK

1.1. A Textile Hierarchy

Textiles are materials that are ubiquitous in our daily lives, from the clothes we wear to the environments that surround us. They provide us with protection, comfort and support. The textiles of today are changing as they undergo a radical transformation in expression and functionality, "[t]hese new textiles are at present located somewhere on the border between design, art, haute couture and research" (Worbin, 2010, p.14). Acting as an interface between textiles and technology, the traditional methods of textile fabrication are now combined with advanced technologies in the creation of smart fabrics. It is clear that, "[w]e are living through a period of unprecedented material innovation that looks set to change the role and purpose of fabric in our lives" (Colchester, 2007, p29).

Smart textiles (or smart fabrics) can be defined as "…materials and structures that sense and react to environmental conditions or stimuli, such as those from mechanical, thermal, chemical, electrical, magnetic or other sources" (Tao, 2001, p.2-3). These sensing abilities have introduced an extended functionality to textiles due to the inherent transformative nature of textiles. This transformative nature allows smart textiles to "...have intrinsic properties that are not normally associated with traditional textiles…" (Hildebrandt, Brauner & Ziefle, 2015, p.2). This offers the opportunity to develop textiles with a new type of behaviour and functionality, changing the application area and the way we use textiles.

As a hierarchically structured material, the unique architecture of these textiles are being used for their "technical performance and functional properties" (Underwood, 2009, p.157). They not only give form to a designed artefact but also play a dynamic role within the design process. Beginning with fibres and yarns, techniques such as knitting, weaving, lace making and felting construct the textile at a structural level through the interlooping, intermeshing and bonding of fibres. Physical attributes such as tensile strength, durability, elasticity and flexibility are dependent on engineering and structure decisions of the textile. Each level of construction, from the chosen fibre to the fabrication technique, affects the final characteristics of the textile from the technical performance to aesthetics and wearability.

Due to its unique structural and tensile properties the technique of knitting warrants particular consideration in developing smart textiles. Knit fabrics are created through a series of interlocking loops known as stitches. The series of intermeshed loops are produced by the knitting needles. Knitting is divided into two distinct types; weft and warp, where each vertical column of stitches is known as a wale and a horizontal row of stitches is called a course, refer to Figures 1.3 and 1.4 (Humphries, 2004). Weft knitting is the technique used to develop the knitted fabrics and sensors. Full control over the knitted fabric through the adaption of stitch length, stitch structure, gauge of machine, and yarn density, allows for a variety of fabrics ranging in weight thickness and structures to be constructed. As a result, the versatility of knitting has become a prominent technique for the construction of smart textiles, opening new possibilities for this Traditional fabrication technique.

New types of fibres and yarn structures have also contributed to the development and performance of smart knitted textiles. The term fibre describes a unit that forms the basis of a textile structure. Textile fibres consist of two distinct groups, natural and manufactured. Natural fibres are directly obtained from an animal, vegetable or mineral source readily useable for textile production. Manufactured fibres, regularly termed, man-made fibres, consist of polymers that are 'spun' or extruded through a spinneret which are then coagulated into filaments. Fibres are manufactured or processed into yarns which are used to construct the textile. Textile fibres come in a staple or filament form. Filament fibres refer to fibres of a long continuous length while staple fibres are relatively short. Natural fibres are classified as staple with the exception being cultivated silk. Manufactured fibres can be either staple or filament, processed first as a filament fibre before being cut into staple fibre lengths toward the end of the manufacturing stage (Humphries, 2004). It is through the processing of fibres that new innovative yarns and fibre developments are being explored, pushing the boundaries into new areas of sensing textiles.

Fibre innovation and development has become a catalyst for textile innovation (Underwood, 2009). With a revolution during the Twentieth Century resulting in the manufacturing of synthetic fibres (Nylon and Polyester) the development of glass and aramid fibres (Kevlar) closely followed (Gohl and Vilensky, 1993).

Figure 1.1. Fisher, H. (2016). Knit Structure.

Figure 1.2. Fisher, H. (2016). Felt Structure.

Today's advancements within technology have seen the emergence of nanofibres and microfibres which have a fundamental significance within today's technological revolution. The development of nanotechnology makes way for functionalised fibres that possess special properties such as fire retardancy, antibacterial and conductivity (Rivero, Urrutia, Goicoechea, & Arregui, 2015). Through conventional and non-conventional methods, fibres are now becoming sensitive to mechanical and chemical stresses making way for intrinsic modification within the textile structure (Castano & Flatau, 2014). New fibres, such as those used within conductive yarns, are made from metal fibres, specifically copper, silver and stainless steel. Metal wire is a common electrical conductor, the movement of electrically charged particles results in electrical conductivity. Conductivity corresponds to the conductance of a material, and is the opposite of resistivity. Resistivity which is measured in ohms per metre is an inherent property of a material, however

Figure 1.3. Fisher, H. (2016). Course, a horizontal row of stitches.

Figure 1.4. Fisher, H. (2016). Wale, A vertical column of stitches.

Figure 1.5. Fisher, H. (2016). Filament yarn.

Figure 1.6. Fisher, H. (2016). Staple yarn.

the resistance of an object depends on the size, shape and length of the item. Properties of copper allows this metal to be malleable and ductile while achieving excellent conductivity of both electricity and heat. Copper's extremely good conductivity properties make it ideal for electrical equipment such as wiring which has become its most common application. Silver has excellent conductivity that exceeds any other metal, however, the high cost of this metal prevents its use in electrical functions (Lenntech, n.d.).

The design of smart textiles at a construction level, within both yarn innovation and textile structure, means "[s]ensing elements can be incorporated into fabrics at any level depending on the structural fabric element being modified or sensitized" (Castano & Flatau, 2014, p.1). The importance of textiles construction within smart textiles is critical, "it will determine the type of bond needed for mechanical attachment to the fabric in the case of externally modified textiles, or the type of constituent element modification required for a more intrinsic integration" (Castano and Flatau, 2014, p.2). This raises the issue of the need for the acquisition of technical knowledge of technologies and materials which expand beyond traditional textile design knowledge into an interdisciplinary arena. Smart textiles have foundations within a range of research fields; textile design, physics and engineering (Berglin, 2008). The significance of smart textile research is in its interdisciplinary approach with traditional techniques, once classed as handcraft being adopted by scientists, engineers and textile designers. This has the potential of transforming textiles into high-tech sensing surfaces with numerous uses in both human and animal healthcare.

1.2. Smarter Healthcare

Smart textiles are an emerging area experiencing huge global growth within the healthcare industry. In 2013 the global market revenue for smart textiles was expected to grow 21.54% per annum, reaching over $2 billion by 2018 (Market & Markets, 2013). The progressive growth and development of smart textile technology has led to its appearance within healthcare applications (Chan, Esteve, Fourniols, Escriba and Campo, 2012). Healthcare and wellness has now become one of the dominant areas of application for smart textiles. As a result of escalating healthcare costs coupled with ongoing technological advancements, it is proposed that smart textiles may change the face of healthcare (Chan et al, 2012). The possible sensing options expand to pressure, tensile and electrical sensing which can provide the healthcare industry with the opportunity to monitor heart rate, breathing frequency and temperature through textiles.

According to their sensing function, smart textiles can be separated into passive, active and very smart materials. A passive smart textile has an environmental or stimuli sensing function; active smart textiles contain an actuator, which allows the textile to sense/detect a signal and react; textiles with an adaptive function are called very smart materials and can sense, react and adapt appropriately to their environment (Stoppa & Chiolerio, 2014). To maintain a sensing function these textiles contain a sensor, actuator and a controlling unit or processor (Tao, 2001).

The presence of a sensor within a smart textile is essential; it is the fundamental element of its sensing function. The level of integration to create a sensing functionality can be either extrinsic or

Figure 1.7. Fisher, H. (2016). Intrinsic modification within textile structure via knitting.

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Figure 1.8. [Extrinsic modification of textile structure (E-textiles)]. (2016). Retrieved May 2, 2016, from https://www.facebook.com/TextileAndDesignLaboratory/photos/pb.293530150782609.-2207520000.1464422914./758567050945581/?type=3&theat

intrinsic. Extrinsic modification refers to the attachment of sensing elements to the textile and can often be referred to as electronic textiles (E-textiles). They alter the characteristics of the fabric through the external attachment of electronics such as resistors and other electronic components. Intrinsic modification however, consists of the internal integration within the textile structure. The characteristics and properties of the fibre play a major role in defining the surface, physical appearance and characteristics of the textile. The use of fibres and yarns that are sensitive to the detection of mechanical and chemical stimuli can be used to create the sensing function within the textile (Castano & Flatau, 2014). These yarns are commonly made or coated with silver or stainless steel to give them their conductive properties. Passive and active sensors can be made intrinsically through the use of conductive yarn and fibres. As this method of integration involves the construction of the sensor within the textile, the textile fabrication is crucial and determines the mechanical connection between the sensing components. Fibres are designed and chosen for their technical and performance properties whether its strength, absorbency, thermal properties or durability.

It is clear that, “[t]he ubiquitous nature of fabrics makes them an ideal vehicle for the design of sensors that are in direct contact with human beings” (Castano & Flatau, 2014, p.1). The ability to interact with the body provides a novel means to sense the wearer’s physiology and respond accordingly. Textiles conforming shapes and their closeness to the human body promotes the opportunity to react to biological responses such as heart rate and breathing frequency whilst being non-invasive and discreet.

Other than providing a platform for the construction of smart sensors, the technique of knitting is aiding in the improvement of the appearance and functionality of current smart clothing. For instance, Fashion Design Professor, Genevieve Dion is combining fashion design with wireless technology when designing the bellyband. The Shima Seiki knitting machine allows the incorporation of conductive yarn and Radio Frequency Identification technology (RFID) to produce a ‘bellyband’ with the ability to monitor uterine contractions and foetal heart rate (FHR) ("Drexel Researcher Develop Smart Belly Band", 2014). Current technology aimed at foetal and uterine monitoring requires women to attend a hospital or testing centre to be hooked up to a tocodynamometer, "[f]or high-risk pregnancy situations these visits can be quite frequent and inconvenient. The technology is also limited in what it can monitor and in some situations, rather invasive" (O, Montgomery, as cited in "Drexel Researcher Develop Smart Belly Band", 2014). The bellyband, which is currently in the prototype stage, incorporates a combination of electrically conductive and nonconductive yarns that are seamlessly knitted across the centre of the band to create a RFID knitted antenna, which can be seen in Figure 1.9. (Roberti, 2014).

Biopotential recordings in the form of electrocardiograms (ECG) are an indispensable and vital tool for both medical and research purposes. ECGs have a significant importance within medical and healthcare where it is a primary diagnostic tool for people with cardiac diseases, providing the practitioner with physiological information about the patient. Ag/AgCl, the traditional form of electrodes used to gather biopotential reading require the use of conductive gels to create a conductive path between the electrode and the patient's skin (Chi, Jung & Cauwenberghs, 2010). However, the use of traditional Ag/AgCl electrodes can provoke skin irritations while the accuracy of a constant signal tends to degrade over time when used for constant monitoring (Taji, Shirmohammadi, Groza and Batkin, 2014).

Intrinsically developed sensors are beginning to emerge in the form of conductive textiles that are constructed through weaving, knitting or embroidery to transform conductive surfaces into textile electrodes. As these electrodes are textile-based their characteristics act like an ordinary fabric, soft and ductile, lightweight and washable without causing skin irritations, making them appropriate for long term constant monitoring applications. Their easy integration into a smart textile garment would make these electrodes suitable for long term monitoring. Taji, Shirmohammadi, Groza and Batkin state that the use of textile electrodes are increasing in demand because of easy use and the convenience of not having to change the electrode during long term monitoring, unlike traditional electrodes

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Figure 1.9. Lee, E. (2014). Belly Band. Retrieved October 20, 2015, from http://www.newsworks.org/index.php/local/healthscience/68231-drexel-team-develops-belly-band-to-monitor-contractions-of-pregnant-women

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Figure 1.10. Zephyr. (n.d.). Zephyr BioHarness. Retrieved April 16, 2016, from http://www.zephyr-technology.nl/en/product/71/zephyr-bioharness.html

(2014). The integration of these textile electrodes within monitoring devices are starting to emerge, where they are becoming a valuable asset to emergency services and the healthcare industry.

First developed for the military, first responders and human performance the Zephyr BioHarness "…can collate information on multiple integrated physiological and activity variables which can be assessed in real-time or post-performance" (Zephyr, n.d.). Through the use of smart textile sensor technology the elasticated lycra chest belt, which contains silver conductive fibres, can monitor ECG, breathing rate and skin temperature. Its monitoring abilities can be adapted for specific needs for both continuous and part time monitoring, recording and transmitting data via radio or other wireless networks. In 2010 the BioHarness assisted in the rescue operation of the 33-trapped miners in the collapse of the San Jose mine in northern Chile. The device was worn by the miners during their time trapped underground, allowing baseline data to be collected helping to create individual profiles on the miners to monitor signs of stress, anxiety, fatigue, malnourishment or hypothermia (Zephyr, n.d.). The availability of new technology such as wireless transmitters and non-invasive micro-sensors are proving to be a valuable monitoring tool, one which has now emerged within animal care.

1.3. Extending Applications

Assessment of animal health is one of the oldest and most significant applications of ethology (Weary, Huzzey, von Keyserlingk, 2014). Information around the monitoring of temperature, pulse, respiration rate and activity can be used to assess an animal's response to treatment or used to identify an early onset of illness (Edwards, Gibson, 2012). Technology is now beginning to replace prior reliance on observations from which to base advice and treatment, providing help in the detection, prevention and treatment of illnesses. The pulse rate in a horse which "…is characterized by the rate, rhythm, intensity, amplitude and duration" (Coumbe, 2012, p.158), can vary between 25 and 240 beats per minute (bpm). As environment temperature, physical condition, age, pain, excitement or fear can affect the pulse rate a prolonged increase in heart rate can be an indication of illness such as a sign of colic (McCall, 1999).

The accessibility of current heart rate monitoring tools within the equine area has appealed to trainers and owners within the elite sport sector. The demand for top performance from equine athletes, particularly within the racing industry, has drawn their attention to monitoring devices such as the E-Trakka blanket and Polar Equine product range. These accessible devices provide owners and trainers with accurate details during and after training sessions with very little preparation. The knowledge gained by the trainer in regards to heart rate, speed and stride length are gathered while the device is worn enabling them to make more informed decisions regarding future training sessions. The information gathered by the devices provides a snapshot of a horse's physical condition. The sensing devices, which consist of two electrodes, which are placed under the saddle and girth are in most cases, not integrated within a product consisting of plastic electrodes and wires. Although Polar has now released the Polar Equine Belt, which integrates the sensors within the strap, the electrodes are still plastic based and the belt can require additional equipment to hold the strap in place. Despite the fact that Polar Equine devices are aimed at the equine industry, the devices do state that the product is optimised for human athletes and that some features may not give reliable readings used on animals.

Early integration of electronics into equine equipment is an area of investigation discussed by McGreevy, Sundin, Karlsteen, Berglin, Ternstrom, Hawson, Richardsson and McLean (2013). They suggest that a multidisciplinary approach to textile research, veterinary and equitation science will allow us to investigate and address problems in order to achieve a higher standard of equine welfare and performance. The significant potential for smart textiles to be incorporated into the design of the next generation of devices could allow the ability to measure pressure, tension, moisture and heat. McGreevy et al. discuss its potential impacts on equine welfare highlighting the use in which smart textiles would be beneficial for monitoring activities such as breathing, extensions of joints, cardiac function and behavioural training (McGreevy et al. 2013).

Within the equine sector, rugs and blankets along with saddle pads, bandages and wraps, are often used to protect horses from deleterious effects of the weather, their environment or other equipment/tack. Saddle pads which were originally designed to protect the saddle by keeping it clean are today used to reduce pressure on the horse's back and muscles caused

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Figure 1.11. Thomas, R. (2012). [Etrakka saddle blanket]. Retrieved November 12, 2015, from http://www.heraldsun.com.au/sport/superracing/paul-messara-uses-futuristic-analysis-to-prepare-ortensia-for-royal-ascot/story-fn67tkww-1226354256244

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Figure 1.12. Polar. (n.d.). Equine H7 heart rate sensor electrode base set. Retrieved May 20, 2016, from http://www.polar.com/nz/products/equine/accessories/equine_H7_heart_rate_sensor_electrode_base_set

Figure 1.13. Fisher, H. (2015). Saddle and saddle pads.

by the saddle (Kotschwar, Baltacis & Peham, 2010). The textiles and fibres used within these products help accommodate and provide protection. Equine products are expected to provide warmth, breathability, be wind and waterproof; while having the ability to withstand rigorous outdoor life. These expectations have introduced the use of synthetics over traditional fibres such as wool, jute and canvas. Synthetic materials like ballistic nylon, polyester, ripstop nylon and polypropylene are sometimes seen as favourable due to their resilience, lightweight, water and stain proof properties. However, traditional fibres such as wool are a time-honoured options because of its wicking, breathability and multi-climatic properties which are not present in synthetic fibres. "The presence of moisture, as a result of sweating or rain leaking ... makes the skin more vulnerable to the effects of pressure, shear and friction forces" (Clayton, Kaiser & Nauwelaerts, 2010, p.52). The result of pressure and friction between the skin and product can cause rubbing or pressure sores making the design and consideration of textiles used an important aspect of these products.

However, one of the challenges this technology faces is the technological barrier between the limitation of current sizes of sensors, electronics and available battery technology that make physiological monitoring difficult. Although in a human based context, Joanna Berzawska (2005) states that…

> "It is ironic that although they are powerful, these wearable computers are not very wearable. Their various components are made of hard plastic, metal, and silicon. They are heavy and angular. Their weight is uncomfortable for extended use and the advantages of wearing such devices are not clear to a majority of people … [m]aterials need to change, functionality needs to evolve past the point where wires hang along the user's body, and the computer housing (the clothing) needs to be more attractive. Most importantly, the wearable computer needs to be less fragile." (p.61).

Textiles today are still just as much about aesthetics as they are about functionality, no matter their application. Good design choices when integrating sensors are going to require an interdisciplinary approach, which acknowledges an inherent understanding of materials, functionality and the design process thereby helping identify new choices for future wearable technology developments. Combining smart textiles with standard horse equipment could provide accurate data collection and measurements, delivering reliable results without causing distress to the horse with the integration of sensors into familiar and comfortable tack.

Figure 1.14. Fisher, H. (2015). Equine natural fibre rug.

METHODOLOGY

2. METHODOLOGY

2.1. Research Through Design: An Iterative Process

A practice-based, research through design approach has informed the methodological design of this project. Research through design was identified by Frayling (1993) as a process where design and practice are the vehicle for the research and a means of communicating the results. While primarily using this action research approach, this project also utilised mixed methods drawn from both qualitative and quantitative paradigms. This approach to data collection uses both qualitative and quantitative methods to help validate data from different perspectives. When using two or more approaches to data gathering such as interview, observations and questionnaire, this method is called triangulation. Triangulation, helps to achieve a variation of perspectives to be explored and discussed using the mixed methods approach to explore and gather data from a range of sources (Teddlie and Tashakkori, 2009).

Phases of the design practice utilised the mixed methods approach from areas of social science, design technology and science. The systematic processes of Action Research permitted the outcomes of the research and practice to be fully investigated in regards to its appropriateness to the context. The exploratory nature of Action Research which was suited to resolving problems that required adaption and refinement, supporting the making and learning from changes as the research progressed. As stated by Swann (2002) "[a]ction research has an established methodology for documentation that can serve as a useful model for design" (p. 58). The design process which, acquired an iterative approach, allowed problems to be revisited, re-analysed and synthesised to help provide solutions. The cyclic process procured the research between phases of experimenting, developing, trialling and reflecting, until a desired outcome was achieved. This cyclic process can be seen in Figure 2.1

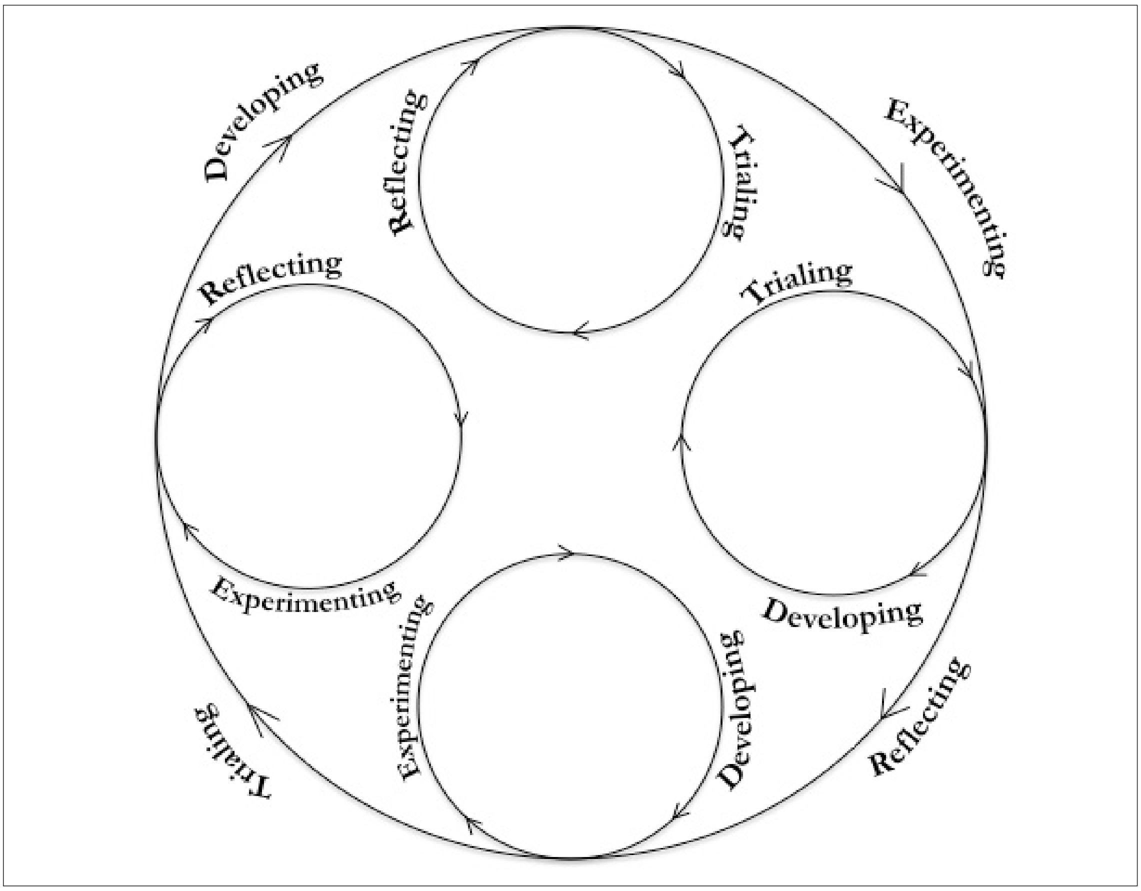

Figure 2.1. Fisher, H. (2016). Iterative cycles of action research.

2.2. Methods of Design Research

This research design project utilised various methods and approaches through iterations of data collection, analysis, reflection and artefact development. Data collection was used as a means to understand equine 'needs' from a professional equine perspective. It was gleaned using a questionnaire, observations and interviews, which through the identification of issues led to the second phase of current artefact analysis of equine-based products in the market place. The assessment and reflection on this initial research phase led to the design development stage, which included aspects of qualitative research. Analysis of fibres and textile structures resulted in prototyping during the final design stage.

2.2.1 Data Collection

An important aspect and a focal point of this research was data gathering through consultation with equine health experts to provide a deeper understanding of the equine industry in relation to the potential use of smart textiles in current equine welfare. A qualitative approach was applied to this research in the form of a questionnaire, semi-structured interviews, field notes and observations which were gathered from professionals within the equine industry. Qualitative Research allows for an open-end approach which provides participants with the choice to direct their interview/s in a direction that suits their own experiences. Crouch and Pearce (2012) state that "[a] key intention of much qualitative research is to provide a vehicle through which participants' voices can be heard" (p. 70). The inductive nature of this method allows the qualitative data to be analysed in an exploratory and iterative manner, which identifies important patterns and themes within the research (Crouch & Pearce, 2012). Data collection was gathered in the form of written and spoken text and contained the words of participants along with written researcher observations. Observations accompanied the questionnaire and interview data to provide personal insights that were not evident within the written responses of the veterinarians. As the process of observations is reflective, "[t]he very process of observing becomes loaded with the theories of the world that the researchers carry with them" (Dunne, Pryor & Yates, 2005, p. 67). The collection of neutral and objective data is impossible as the observer will unconsciously shape the data through what they see as important. The collection of qualitative data in this project was carried out to inform the design development process by identifying a 'need' and potential applications of use of textile-based sensors within the equine sector. This process was also documented in the form of a journal that recorded research findings and reflections. Newbury (2001) explains that a journal acts as "...a self-reflexive and media-literate chronicle of the researcher's entry, participation in, and departure from the field" (p. 7).

2.2.2. Artefact Analysis

Analysis of equine-based materials, textile techniques and human and equine-based products contributed to an understanding of their physical, anatomical and functional properties. Through an analysis of these areas, a deeper understanding of each aspect was gained, and these findings directed the design development process. Swann (2002) states that "…when reflection is coupled with analytical thinking for further enactment, it can contribute new knowledge that resides within the realm of research" (p.60). Analysis and reflection became a useful tool when examining and comparing fibres, fabrication techniques and current products, within both the human and equine sectors, helping to interpret features that could suggest possible areas of development or desired attributes. Reflection after the process of mind mapping provided a method of understanding and visually organising sections of the research. Mapping the areas of equine materials and smart textile systems helped generate ideas and develop concepts by identifying relationships between components and promoting an understanding of interconnecting parts within the information. The mind mapping process can be seen in Appendix A, mind map of Equine Rugs and Appendix B, mind map of Smart Textile Systems.

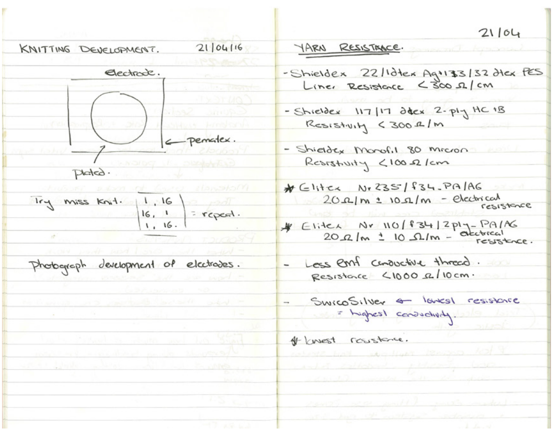

Figure 2.2. Fisher, H. (2016). Notebook.

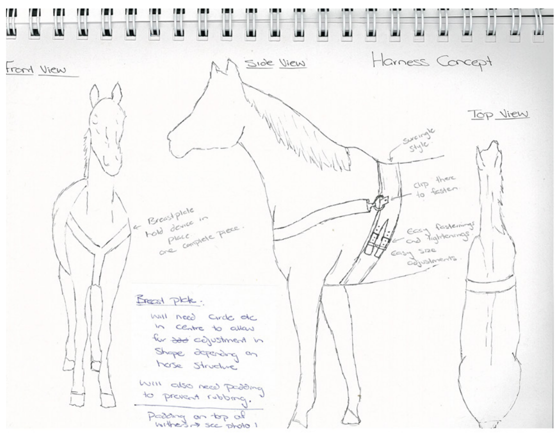

Figure 2.3. Fisher, H. (2016). Sketching..

2.2.3. Design Process

Iterative design was used throughout the design process where experimentation was a fundamental aspect of discovering an appropriate design solution for both the practice and the research. The iterative design process is discussed by Swann (2002) where he reviews the evolutionary design process as a mode of working in which to formulate solutions. This cyclic design process was implemented within the experimentation of the materials phase of fibre to fabric development. Here the process of experimenting, developing, trialling and reflecting on which yarns and fabric structures were to be developed and examined was undertaken. The cyclic iterative manner of action research allowed the process within the development stages of fibre trials through to prototype development to accommodate the introduction of new knowledge and design iterations to be incorporated into each new phase.

2.2.4. Qualitative Research

The process of trialling new yarns and developing new fabric structures drew on scientific research principles during the subsequent Quantitative Research stage. The approach focused on the collection of technical (numerical) data about the electronic and mechanical properties of the textile samples to develop theories and hypotheses regarding smart textile structures and yarn configuration. Statistical analysis of this data revealed patterns and repeatability of the conductive fabric samples which acted as a directory, with this information providing a basis for yarn and structure choices throughout the project. Quantitative data gathering and analysis was conducted through collaboration with Master of Engineering student Yasir Al-Hilali. This interdisciplinary collaboration enables a sharing of expertise. The area of interdisciplinary problem solving was maximised in a collaborative setting where an understanding of the intersections between textile design and mechanical and electrical engineering led to a productive area of research where new knowledge emerged.

2.2.5. Reflection in Action

The development of practical and relevant solutions concerning fibre choices and product shaping evolved from reflection in-action during iterative stages of the project, this method was a way of thinking and interpreting. The method of reflection in-action was proposed by Donald Schön in his book The Reflective Practitioner (1983). This critical strategy of reflection in action and on action draws on experiences and the reinterpretation of information as an agent of change. The reflection of information and processes from multiple areas throughout this research produced new knowledge as an outcome of iterative design stages.

2.2.6. Prototyping

The creation of tangible artefacts throughout various stages of development and experimentation permitted the testing of ideas to be achieved through the method of prototyping. A critical stage of the design process is creating a physical depiction of concepts, "…representing the creative translation of research and ideation into tangible form, for the essential testing of concepts by the designer…" (Hanington & Martin, 2012, p.138). Prototyping was used throughout the design process when developing fabric, sensors and the product shape. The use of prototypes in iterative design allowed for early testing of ideas, which first appeared as concept sketches and storyboards during the beginning of product ideation. These concept sketches become physical and more refined throughout the experimentation process, with prototypes becoming a representation of the final product while testing their functionality.

Figure 2.4. Fisher, H. (2016). Studio storyboard.

DESIGN PRACTICE

3. DESIGN PRACTICE

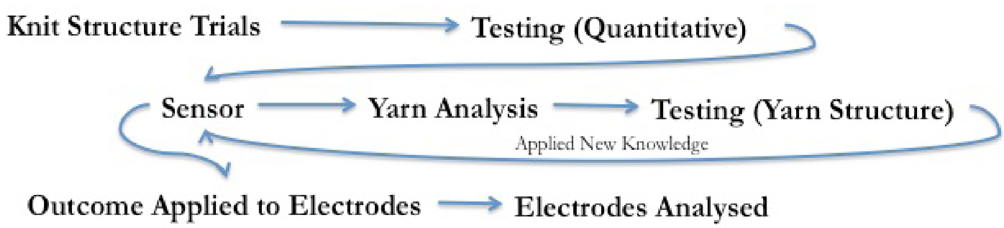

Figure 3.1 Fisher, H. (2016). Textile sensor development process.

This Project is developed around the integration of the functional and technical. Design aspects shape the use of smart textile in the translation of this technology into an equine-based product for the continuous monitoring of heart rate. The design practice phase of the research operates on a multiple level design inquiry, driven by a technical development investigation into the construction of textile-based sensors. Functional aspects during sensor and fibre analysis informed base fabric development and the integration of electronics leading to a working prototype.

Figure 3.2. Fisher, H. (2016). Half cardigan.

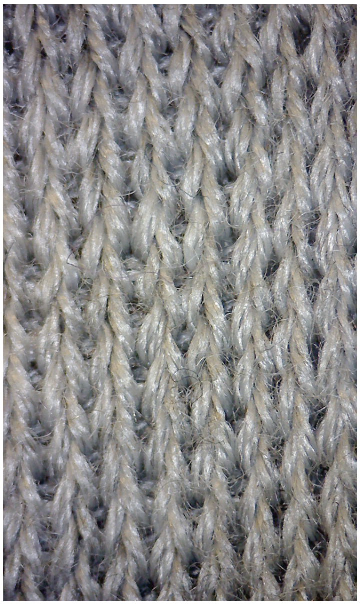

Figure 3.3. Fisher, H. (2016). Interlock.

Figure 3.4. Fisher, H. (2016). Tuck.

3.1.1. Knitted Response: Knitting Sensors

Knitting technology was critical to the process of manufacturing textiles sensors and an important design tool. Construction of textile sensors began through the use of a digital knitting machine. The Shima Seiki knitting machines, utilised in this research, are regarded by many as the most advanced knit-related system available on the global market. By using stitch codes, developed by Shima Seiki, which are represented by a number and colour system, fabric structures were created using this programming language. These fabric structures were programed and 'drawn' on the Apex 3 Design System using KnitPaint within the surrounding fabric, prior to being knitted using the 14 gauge SIG123SV intarsia machine. In an early collaborative project with Caroline Stephen, a variety of stitch structures were used to develop the initial textile sensors which incorporated a combination of both single and double knit techniques using a mixture of plain, purl, rib and tuck stitches.

The intarsia technique used to develop the sensors allowed conductive yarns to be knitted only where the sensor was to be integrated. Textile sensors were able to be isolated within the surrounding based fabric via the intarsia technique. Isolating these knitted sensors optimised placement possibilities of integrating the sensors anywhere within the fabric structure.

The specific design of the conductive yarn within the fabric structure establishes the detection mechanism of

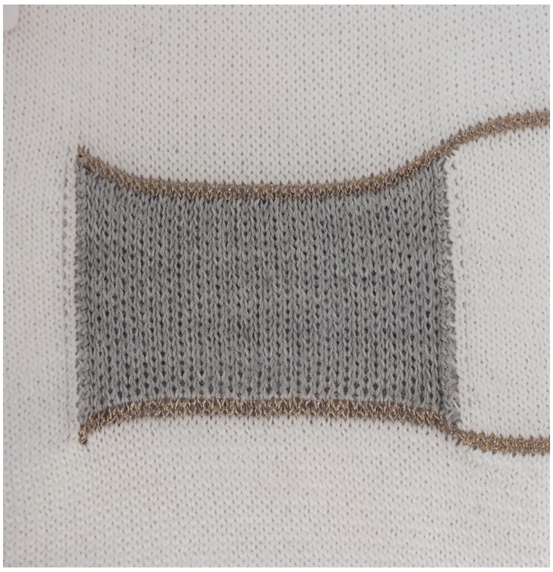

Figure 3.5. Fisher, H. (2016). Isolated knitted sensor.

the knitted sensors through the change of electrical resistance. Extension and compression of the conductive yarns and the contact points within the knitted loop structure change electrical resistance within the fabric (Castano & Flatau, 2014). Therefore, the degree of change in resistance of the conductive yarns is influenced by the fabric structure. Resistance properties of the yarns change when force is applied to the sensor. Initial sensors were developed and tested within the parameters of a set sample size, type of yarn and amount of pressure applied to investigate the influence of different knit structures on the change of electrical resistance.

Two types of yarn were originally chosen to construct the sensors. Conductive yarn consisting of a stainless steel and polyester mixed yarn and a ninety nine percent silver yarn was used to knit the sensor and circuitry. These yarns were chosen for their conductivity and resistance properties, which determined where each yarn was to be used.

Figure 3.6. Fisher, H. (2016). Stainless steel polyester (left) and silver conductive yarns (right).

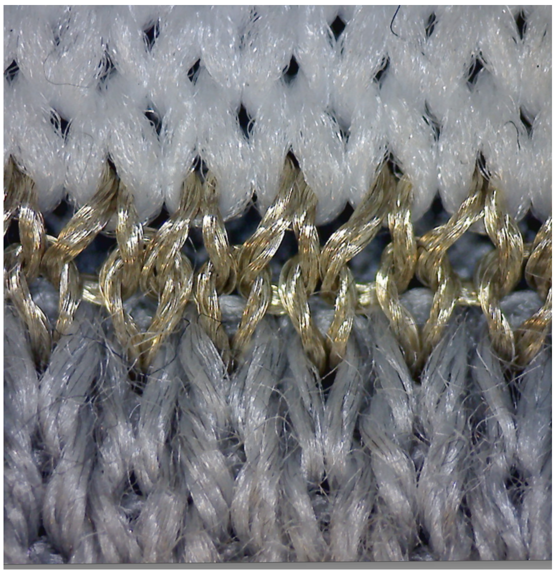

Figure 3.7. Fisher, H. (2016). Close up of knitted sensor and circuitry.

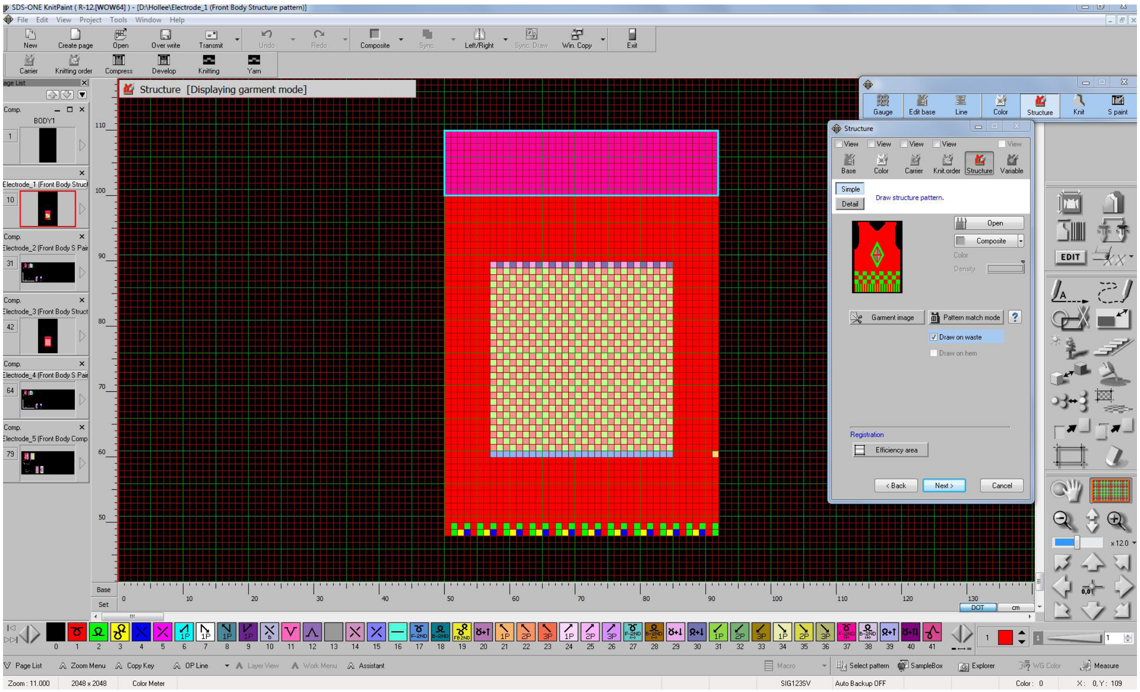

Figure 3.8. Fisher, H. (2016). Interlock structure page in KnitPaint.

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Figure 3.9. Textile and Design Lab. (n.d.). [Shima Seiki SIG123SV intarsia machine]. Retrieved April 29, 2016, from https://tdl.aut.ac.nz/about/knit/

3.1.2. Mechanical Interlocking: Felted Sensors

Felted sensors were created during an experimental trial where stainless steel fibres, which were sourced in the form of staple fibres, were trialled and tested. Non felting fibres, such as stainless steel, can be used in combination with wool to produce a felted fabric. To achieve the felted fabrics a FeltLoom, needle felting machine was used. Mechanical interlocking of fibres can be achieved through a needle felting process that involves barbed needles punching through a fibre batt entangling the fibres. The scales on wool fibres interlock and shrink together when exposed to the felting process. Wool and stainless steel fibres were processed into batts using hand and drum carding techniques. The carding process created a blend of pre-mixed fibres by combining the wool and stainless steel. A variety of felted samples were created which explored pre-mixing and laying of stainless steel fibres in multiple directions throughout the felted batt to determine a method most suited to constructing pressure sensors. The construction and results of testing these felted sensors can be found in Appendix. C.

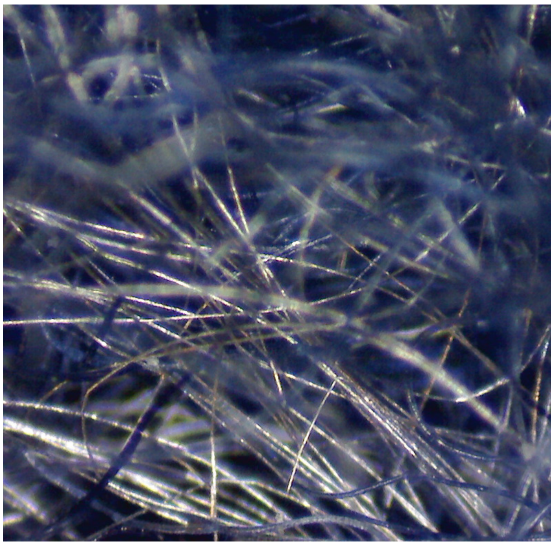

Figure 3.10. Fisher, H. (2016). Magnified view of felted wool and stainless steel sensor.

Figure 3.11. Fisher, H. (2016). Felted sensors.

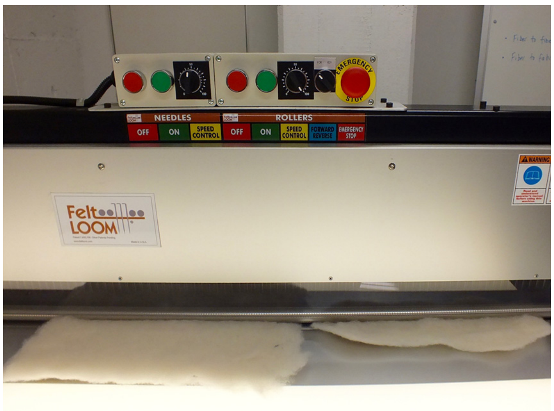

Figure 3.12. Fisher, H. (2016). FeltLoom.

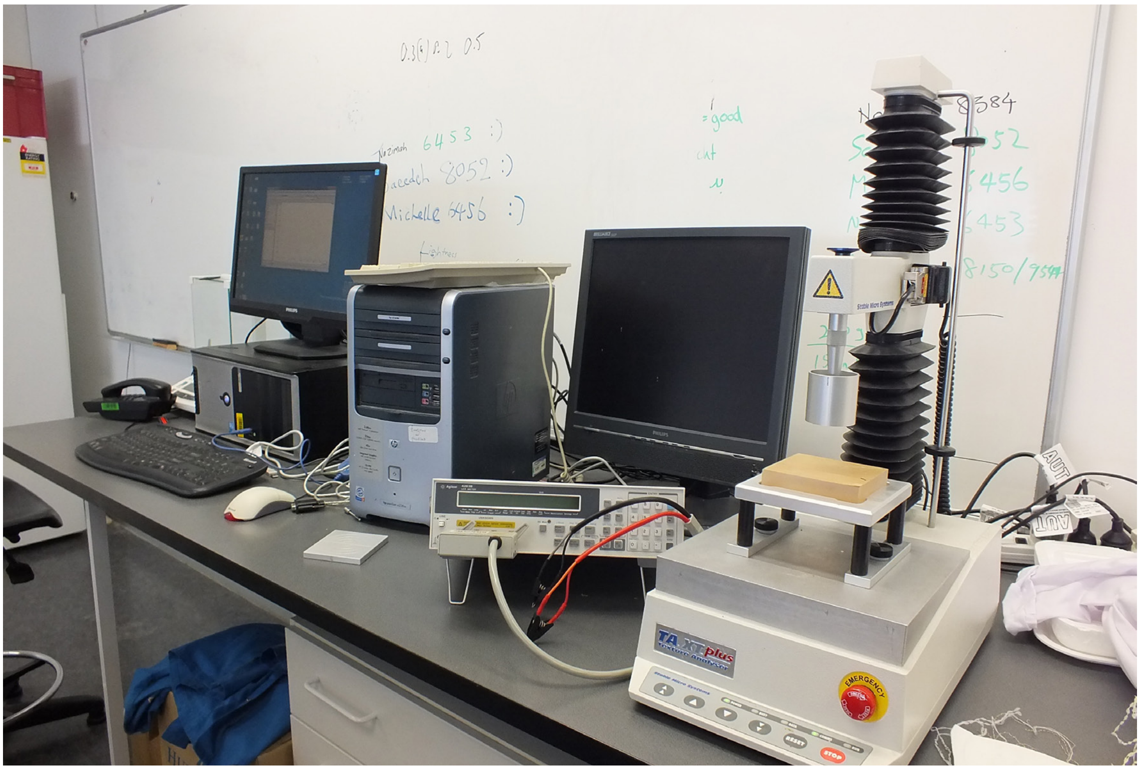

Figure 3.13. Fisher, H. (2016). Sensor testing setup.

3.1.3. Sensing Data: Textile Sensor Testing

After compiling a range of textile sensors which explore both knitting and felting techniques the sensors underwent testing to determine the most appropriate structure. Fabric sensors underwent basic sensor testing using MaxMSP as an initial starting point for analysis during the first iterative stage of sensor development. MaxMSP uses a visual programming language which works alongside an Arduino to import sensor data exporting it to an Excel file in order to push the design process for further analysis. Although this initial testing was not scientific or reliable, it provided a basic understanding of whether or not the sensor could detect and monitor external stimuli.

Stage two of the testing involved the introduction of interdisciplinary collaboration within the project. For this research to fulfil the desired expectations, this project had to expand outside my own knowledge limitations. Throughout multiple areas of this research the crossing of boundaries into other disciplines was necessary. This led to broadened understanding and knowledge of unfamiliar areas. The fundamental need to gain specialised knowledge enabled interdisciplinary collaboration in the fields of engineering, electrical knowledge and veterinary science. This interdisciplinary collaboration necessitated interaction with experts so as to develop new skills and understandings in order push the design process forward.

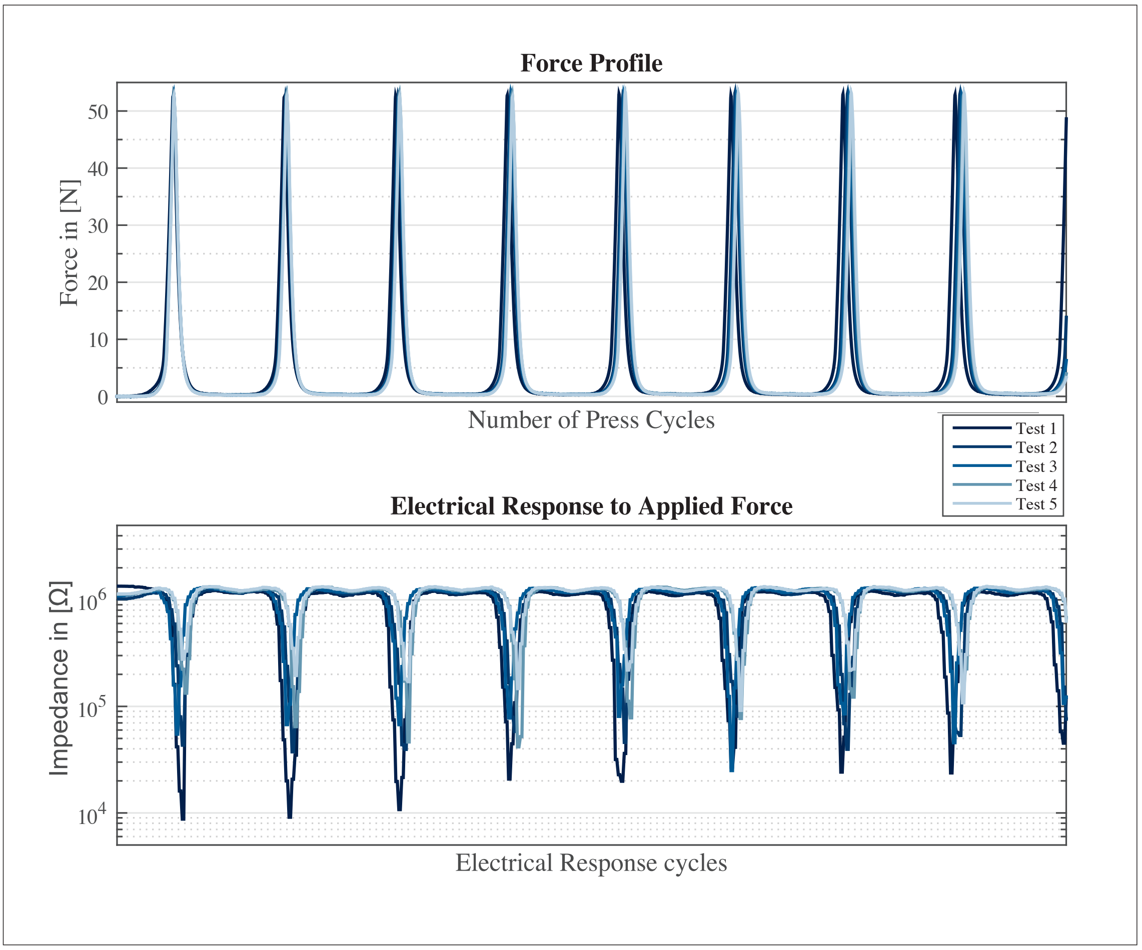

Figure 3.14. Fisher, H. (2016). Knitted tuck sensor analysis graph.

Whilst working alongside Yasir Al-Hilali a viable testing procedure which accurately tested the textile sensors for change in impedance when applying a consistent amount of force was initiated. When subjected to increasing force, the contact between fibres increased. Data was gathered from the knitted structures and the felted fabrics by monitoring the change in impedance.

Quantitative data gathered from the testing was used to formulate graphs comparing the change in impedance to the applied force over the span of five rounds of testing. Through this method of testing, knit structures could be identified for their reliability and sensitivity.

Further information on how the testing was performed and the results can be found in Appendix D.

3.1.4. Conductive Investigation: Yarn Analysis

Currently available conductive yarns with specific technical characteristics such as conductivity and resistance properties were examined in a systematic study. The yarn sourcing investigation was an exploration which determined the influence of specialised yarns on the reliability and impedance properties of the knitted sensors. A variety of conductive yarns were trialled to analyse the use of multiple types of metals with individual conductive properties such as stainless steel, copper and silver. The method of manufacturing these yarns was also taken into consideration. Yarn construction and the technique of metal integration; through plasma coating, blending of staple fibres or filament yarns were the areas studied.

Figure 3.15. Fisher, H. (2016). SwicoSilver plasma coated yarn.

The newly sourced yarns were substituted into the interlock knit sensor structure. When compared to other basic weft knit structures, interlock was found to have the highest dimensional stability. This finding was the rationale for further testing on this structure with the hypothetical reasoning that this property would enhance the reliability of the sensors in terms of repeatability. The yarns chosen were tested alongside both a merino wool and a polyester yarn to determine the effect a natural or synthetic yarn had on the nature of the sensor. The conductive yarns tested and their results can be found in Appendix E.

The newly developed knit samples were subjected to the same yarn testing process as the previous samples. These results informed the next stage of iterative design when the chosen yarn, SwicoSilver, was used in the construction of textile electrodes.

Figure 3.16. Fisher, H. (2016). Polyester and stainless steel conductive yarn.

3.1.5. Textile Electrode

The use of conductive yarn replaces metal pads and conductive gel in traditional electrodes, to fulfill their purpose yarn and structure combinations had to be considered. To obtain a robust heart rate signal a highly conductive yarn is essential to decrease the electrode impedance (Marquez Ruiz, 2011). The yarn analysis phase concluded that the SwicoSilver yarn was an appropriate choice due to

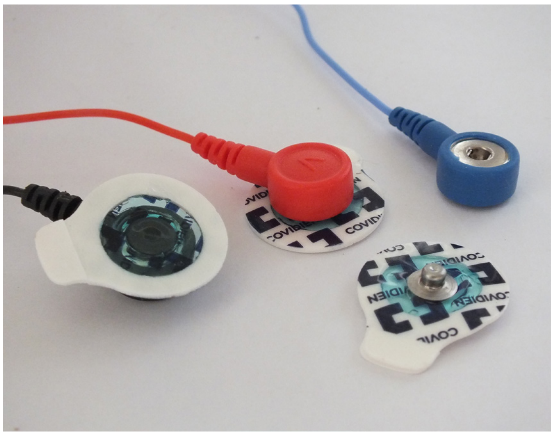

Figure 3.17. Fisher, H. (2016). Traditional Electrodes.

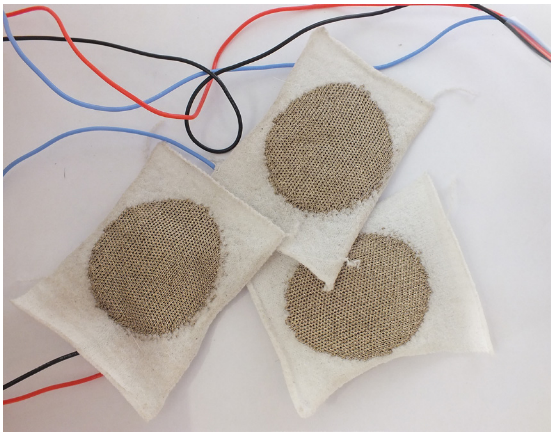

Figure 3.18. Fisher, H. (2016). Textile Electrodes.

it high conductivity properties. As the performance of these yarns have a large impact on the signal quality, the high quality and precise coating of plasma coating was a desired property to this yarn. Textile electrodes do not require the use of conductive gel but a thin layer of skin moisture or sweat helps to provide extra conductivity (Taji, Shirmohammadi, Groza and Batkin, 2014). The hydrophobic nature of synthetic yarns reduces the breathability of the fabric, causing the skin to sweat, in this case the non-breathable nature of synthetic yarns used to construct the electrodes is seen as a desirable property.

Adjustments to a textile structure changes the contact of the electrode with the skin surface and its stability. Movement of electrodes during an ECG recording can disrupt the data reading, causing inaccurate results (Fuhrhop, Lamparth & Heuer, 2009). Traditional electrodes manage this movement by containing an adhesive skin tape that attaches the electrode firmly to the skin, while a stabiliser keeps the skin in its center as still as possible. Knitted stitch structures were trialled when developing the conductive surface of the electrode and a stable surrounding base fabric. Experiments to try and resolve a knit structure which resulted in little movement used structures and techniques such as plating, interlock and miss knit, to create sample electrodes. These samples underwent manual stretch tests during iterative cycles to evaluate their elasticity properties. An assessment of the size and stretch properties were conducted each time a sensor was re-knitted. Re-developments of the knit programming files throughout the iterative stages led to the adjustment of option lines and stitch size. Changing the knitting process in terms of the selection of carriers used, feeder positions and the addition of a package base pattern referred to individual sections of the knit programs that construct the overall design. It was through these cyclic processes that a desirable outcome was achieved and a stable, highly conductive electrode was produced. Further stabilisation of the textile electrodes were achieved by replacing the polyester base yarn used for sample testing with Pemotex yarn. The properties of this yarn causes it to harden when exposed to a steaming process, eliminating any unwanted stretch and movement in the surrounding fabric. The development process of the construction of the electrodes is further discussed in Appendix F.

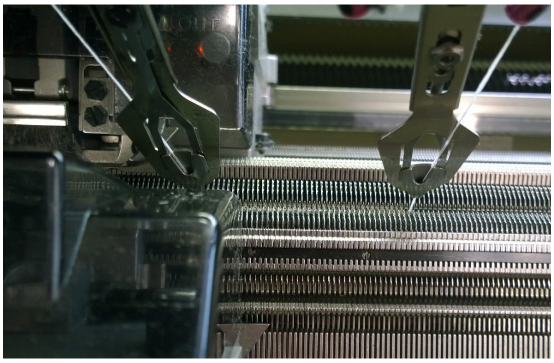

Figure 3.19. Fisher, H. (2015). Needle bed and feeders.

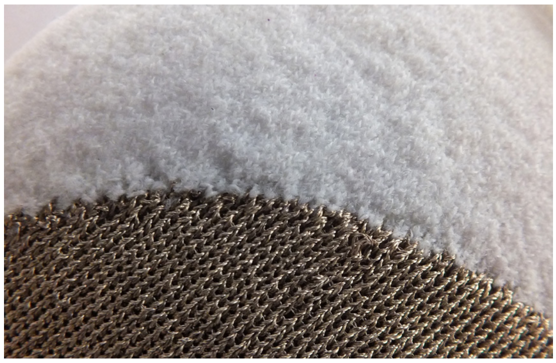

Figure 3.20. Fisher, H. (2016). Knitted electrode using pemotex yarn.

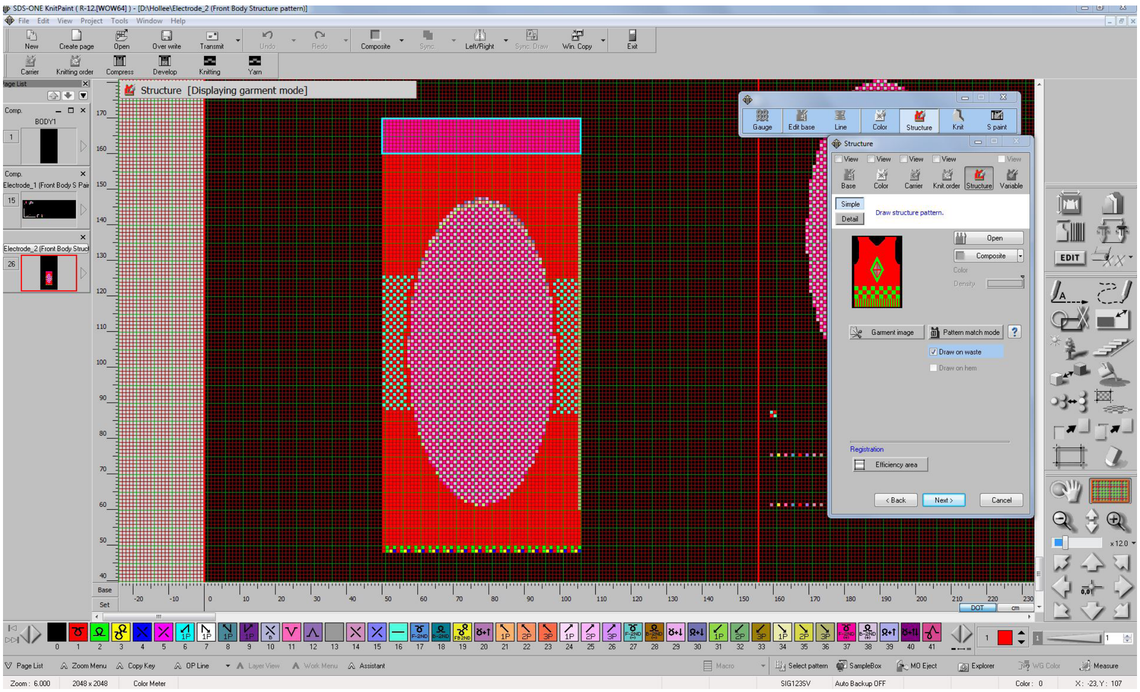

Figure 3.21. Fisher, H. (2016). Structure page on KnitPaint for electrode development.

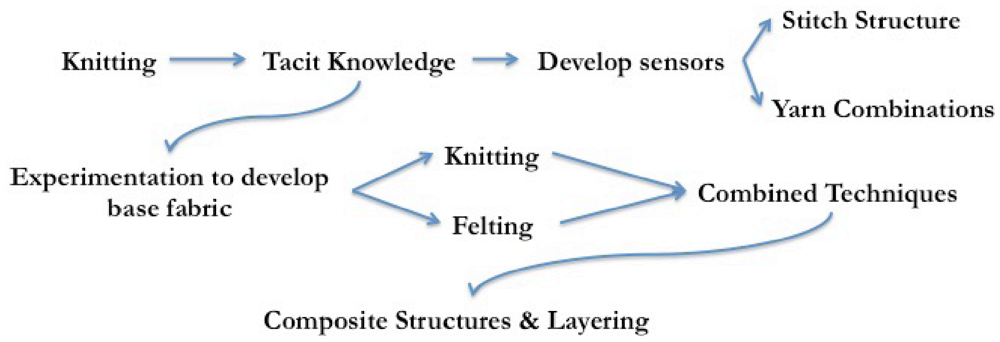

Figure 3.22. Fisher, H. (2016). Base fabric development process.

3.2.1. Textile Composite: Base Fabric Development

An investigation into equine-based equipment provided an understanding of materials that are currently used for horses. This investigation was mainly conducted through practical engagement with equine tack. Blankets, rugs, saddles, girths and other equipment were examined to determine construction techniques, use of fastenings, shapes and types of materials used. A mind map was formulated to condense this new material knowledge while presenting it in a systematic approach. This mind map can be found in appendix A. The product was to be designed as a multiple use device, in terms of being practical for both indoor and outdoor life. This material investigation helped formulate design options in regards to choice of fibres and structures that could be used when designing the textile system to achieve the desired properties.

The development of the base fabric structure was strongly influenced by my tacit knowledge which drove this stage towards knitting as a fabrication process. Philosopher Michael Polanyi (1967) reconsidered human knowledge in his book The Tacit Dimension, where he states that "...we can know more than we can tell" (p.4). He terms this knowledge and phase of thinking as 'tacit knowledge'. Tacit knowledge is an automatic process, it requires little or no thought, it is a process of knowing how to do something without thinking about it. As tacit knowledge can be technical or cognitive, it consists of values, beliefs, perceptions, insights and assumptions which helped determine decision making throughout this research. Previous knowledge gained in stitch structures and yarns/fibres, during my textile degree, proved to be a valuable asset when constructing a complex composite structured base fabric. The multiple techniques used to construct the base fabric is what defined this material

Figure 3.23. Fisher, H. (2016). Magnified view of felted knit composite.

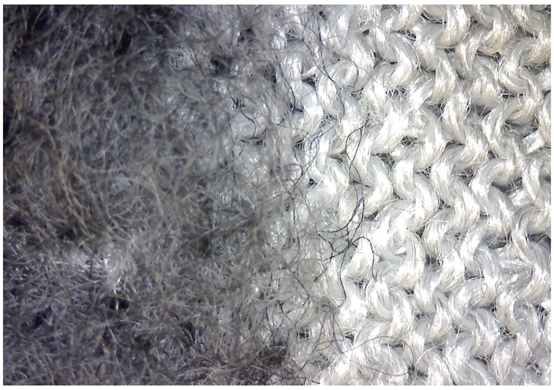

Figure 3.24. Fisher, H. (2016). Composite fabric.

as a composite fabric. The two constituent materials with significantly different physical properties, combine to produce a material with new characteristics which differ from the original individual fabrics (Balasubramanian, 2016). These individual fabrics remain both separate and combined within the finished structure creating a textile that is superior than the sum of the individual materials. These composite fabrics provide a unique opportunity for new applications not traditionally associated with textiles.

The decision to develop a knit based structure originated from the requirement to construct an equine-based product that directly incorporated the textile electrodes. Full control over the knitted fabric through the adaption of stitch length, stitch structure, gauge of machine, and yarn density, allows for a variety of fabric weights, thickness and structures to be constructed. A number of articles based on the use of textile electrodes, state that pressure is found to beneficially affect the signal quality by stabilising the electrode to skin contact improving R-wave detectability (Comert, Honkala, Hyttinen, 2013). Unlike gel electrodes which are stuck to the skin, textile electrodes rely on an externally applied force to secure them in place. By optimising the properties of knitted fabrics, the base fabric was constructed to provide a form fitting material which sits closely against the body. Inherent stretch properties and resilience of a knitted fabric and its ability to recover from deformation, answered these functional needs. Iterative cycles of knitted fabric samples were constructed until the correct amount of stretch and elasticity was accomplished. Through the integration of the textile electrodes within the base fabric, the effect of any disturbances in the ECG measurements due to electrode movement in relation to the skin becomes minimal.

Sections of the textiles composed of the felted structure were used for their inelastic, hard wearing, and strength properties. Felt helped to provide form and stabilisation to the textile, it was also used as an integrated form of padding. The ability to achieve a range of thicknesses through the layering of fibre batts provided the opportunity to develop a suitable level of density. Padding specific areas of the device was required to prevent it rubbing on exposed and vulnerable areas of the horse. Specific areas of the horse, such as the withers and chest, are susceptible to rubbing of equipment due to incorrect fit especially on high withered or fine coated horses (Clayton, Kaiser & Nauwelaerts, 2010). The felted padding was designed within 'Tech Tack' to ensure that pressure on the chest, shoulders and withers was kept to a minimum.

Where possible, it was my goal to use natural fibres as an alternative to synthetics. This preference was prompted by the properties natural fibres possess. As 'Tech Tack' is designed to be worn for long term monitoring, properties such as breathability and moisture absorbency become desirable attributes. Alongside silver's known antibacterial properties, the antimicrobial bio-agent found in natural bamboo fibre, known as 'bamboo kun', contains both antibacterial and antifungal properties. These antibacterial properties of both silver and bamboo provide the textile with a natural bacterial resistant function (Afrin, Tsuzuki, Kanwar, & Wang, 2012). A table of fibres and their properties can be found in Appendix G alongside a fibre investigation in Appendix H, where natural and re-generated fibres were constructed into felted fabrics. The properties these fibres and fabrics provided were not only important in terms of designing an equine-based product, but the way they reacted and complimented the design and function of the sensors. Synthetic and natural yarns were examined in conjunction with conductive yarns to determine reliability and impedance properties of the sensors during the development of the textile sensors. Wool and bamboo as base fabrication fibres work alongside the silver and pemotex yarns used to construct the electrodes. The varying properties of these yarns and fibres, when used in a composite combination, provide the possibility to develop a single fabric that contains multiple sections of distinctly different yarns or fibres, each chosen specifically for their individual properties and qualities.

Figure 3.25. Fisher, H. (2016). Evidence of rubbing on horse.

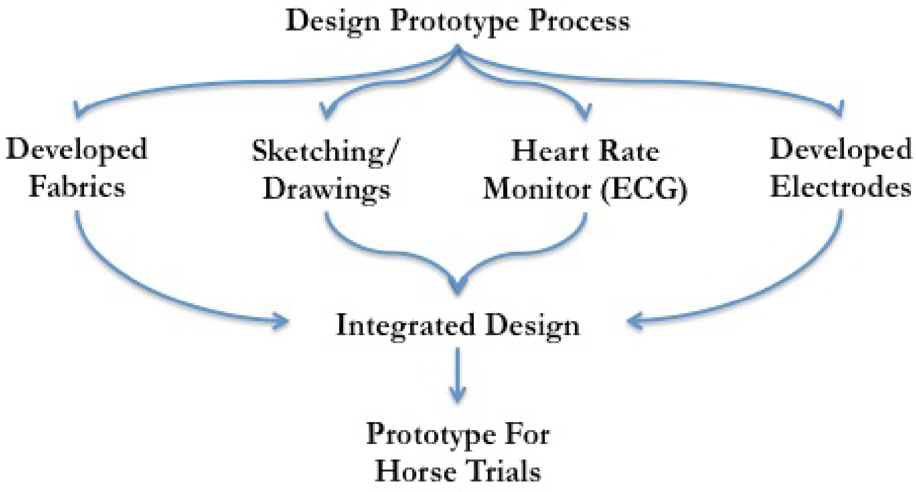

Figure 3.26. Fisher, H. (2016). Design prototype process..

3.3.1. Tech Tack: A Design Prototype

Aspects of previous research and experiments were brought together to form the prototyping stage. The iterative stages of this phase implemented the integration of sensors and developed base fabrics to form the prototype designs.

The majority of this research was bound by ethical considerations which informed the research practices throughout the project. For use of animals within the development phases of prototyping, the research had to oblige by the Animal Welfare Act of 1999. To comply within the guidelines was to ensure the research was conducted ethically making ethical considerations an overarching awareness of every aspect of the research. Ethics approval was also required to engage with participants during the expert inquiry stage where information was gathered to gain further knowledge of the equine industry and guide the research direction. The Auckland University of Technology Ethics Committee (AUTEC) and the University of Auckland Animal Ethics Committee (AEC) provided detailed requirements on how to conduct the research.

3.3.2. Expert Inquiry

The expert inquiry phase, aimed to gather basic knowledge of current methods of equine care and wellbeing while examining the potential integration of smart textiles into the equine industry. A questionnaire to gain professional opinions from equine associates was sent out to a variety of equine clinics, hospitals, veterinarian institutions and breeding studs within New Zealand and Kentucky, America. A 'field trip' to a Matamata breeding stud, provided the opportunity to conduct an initial observational study. The primary intent of this observation was to witness an equine vet conducting regular daily activities, while considering where the incorporation of a smart textile-based device could be of use. During this observation phase an informal interview was conducted regarding follow up questions from the analysis of the questionnaire and possible initial design concepts. Equipment which was familiar to both horse and foal was discussed with a focus on equipment that ensured an uncomplicated design for the vet. The outcomes of the expert inquiry phase narrowed down design decisions which were identified through common issues and areas of

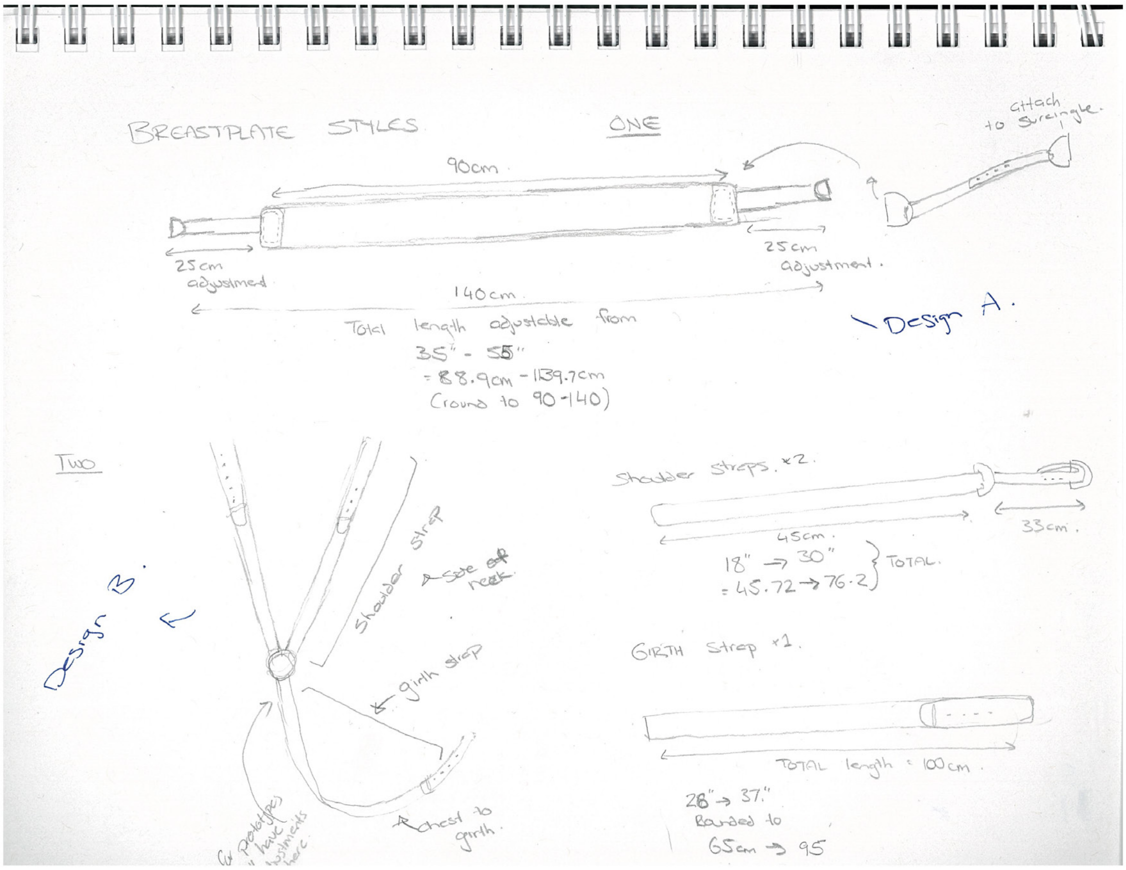

Figure 3.27. Fisher, H. (2016). Equipment concept drawings.

investigation mentioned by the surveyed group of veterinarians. This area of the research formulated the design focus concluding that a textile-based system, to monitor the heart rate of horses would be the design focus. Concentrating on this particular area the research helped direct appropriate design options towards the examination of current tack used around the chest and girth area of the horse.

Further details and analysis of the questionnaire can be found in Appendix I.

3.3.3. Changing Tack: Design Prototyping on the Horse

Design inspiration and practical aspects for the construction of the device was influenced by the material and equipment investigation. The shaping and fit of the device was a fundamental aspect which determines the reliability of the sensors and comfort factor. Shaped equine tack, such as shoulder guards, rugs, slinky hoods along with girths, surcingles and breastplates were examined and chosen due to their association with the area needed to monitor the heart rate. These items of equipment were examined as a result of their fitted nature around the chest and girth area. Accurate measurements were taken of both the equine equipment and the horse which it was assigned to. The measurements taken from the horses were collated together alongside equipment measurements to construct a correctly sized piece of equipment.

With basic knowledge and experience in pattern making, I was able to modify the shapes of the equipment by combining a range of patterns to produce a device that correctly accommodated the areas of the horse where the monitoring would take place.

Sketches in the form of concept designs and ideas acted as a visual communication tool which were drawn from inspiration gathered from the material and equipment investigation. These sketches portrayed moments of thoughts and realisations during the development process revealing the process of reflection as new problems or solutions appeared. As the designs progressed the sketches became more technical as a deeper understanding into the product was developed.

After approval from animal ethics committee on April 6th 2016, the first developed prototype was trialled on a horse. Prior to this, prototypes, sensors and fabrics had not been applied on a horse. Initial prototype shaping started in the form of a surcingle. A surcingle is a strap which runs under the belly and over the back of the horse where it sits, positioned just behind the withers. The placement of this known piece of equine equipment is located within the area needed to monitor heart rate. The prototyping of this shape was trialled on a horse where the re-evaluation of shape, size and extra securing was evident.

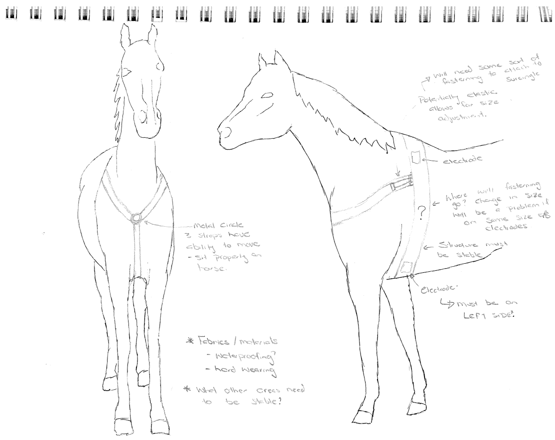

Figure 3.28. Fisher, H. (2016). Concept Sketches.

Figure 3.29. Fisher, H. (2016). Surcingle prototype.

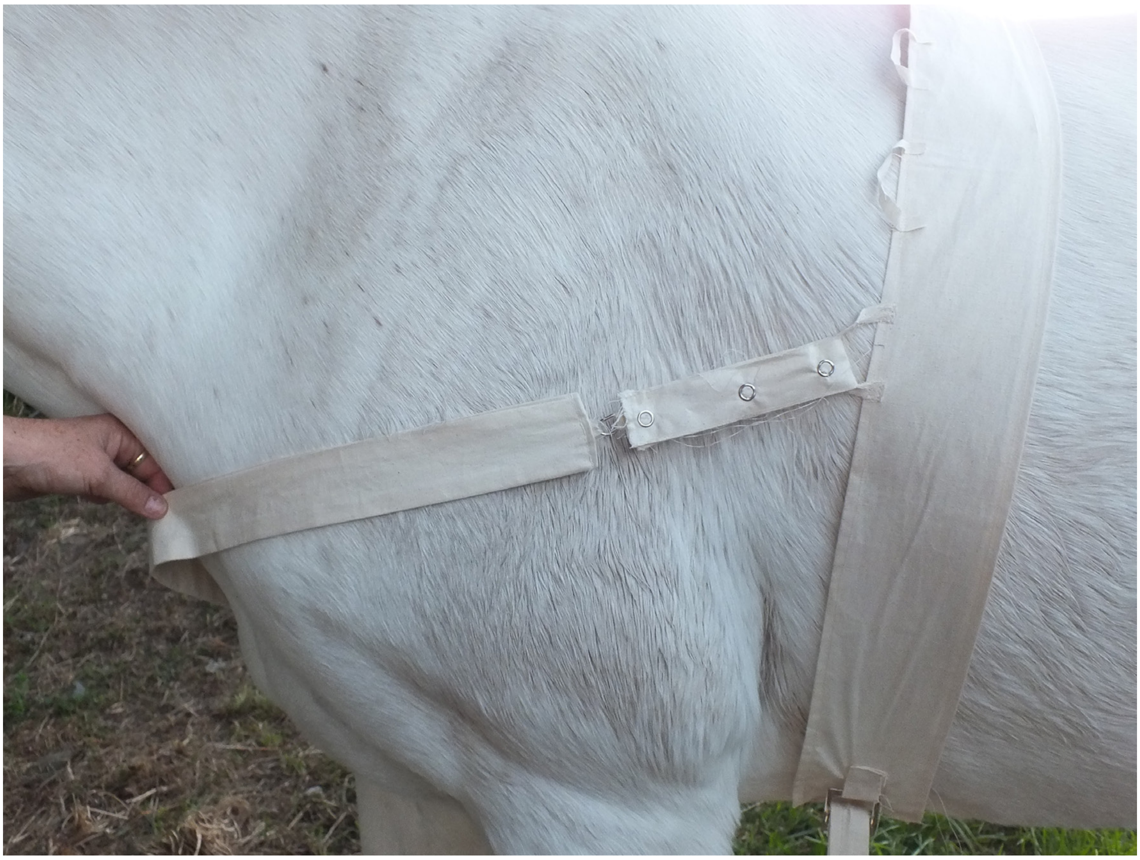

Figure 3.30. Fisher, H. (2016). Breastplate prototype number one.

Figure 3.31. Fisher, H. (2016). Breastplate prototype number two.

The decision to add a breastplate into the design of the device was initialised by the realisation that the piece of equipment could easily be dislodged when exposed to movements and situations such as rolling or running. Breastplates were added to the design of the surcingle using two different styles with the design purpose of holding the equipment in place, preventing it from sliding back and disrupting electrode signals.

Reflection on the initial intent of creating a smart textile constant monitoring device that was easy to use and apply, promoted another phase of the equipment investigation. Further investigation and experimentation led to the development of a prototype which resembled a shoulder guard. The adjustment of the surcingle and breastplate would vary significantly when fitting this device to a variety of sizes of horses causing deformation in the device structure and the specific placement of the electrodes. With a shoulder guard designed to protect the shoulder and wither areas against the rubbing of a blanket, this form of equipment is located in the area of this design application while only consisting of one piece of equipment which is easily applied. The adaption of the shoulder guard, to sit tightly against the horse's body was also modified to sit underneath the belly and chest. Previous designs of surcingles and breastplates would have required minimal stretch properties relying on buckles for size adjustments. Fastenings within 'Tech Tack' became minimal with the elasticity of the fabric accounting for less drastic size change where only one fastening is required. The tight fitting design of this newly designed shoulder guard held the electrodes securely in place, reducing potential movement in the device.

3.3.4. Detecting a Rhythm: ECG Readings

As ECG's are primarily used to detect cardiac arrhythmias, in which the heartbeat may be irregular, too fast or too slow, any lead system may be chosen as long as it generates a distinctive P, QRS and T complex, this complex can be seen in Figure 3.33. To acquire ECG reading from large animals there is no specific lead system that is universally accepted. However, the two leads commonly used to detect a rhythm are the base-apex and Y lead system (Smith, 2014).

The base-apex lead uses three standard bipolar leads. The positive (+) electrode is positioned on the horse where the apex beat is most readily palpable, usually on the left thorax in the fifth intercostal space, (the space between two ribs), level with the horse's elbow. The negative (-) electrode is attached to the top of the right scapular spine (the shoulder blade).

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Figure 3.32. Ashley, E, A., Niebauer, J. (2004). The basic pattern of electrical activity across the heart. Retrieved May 30, 2016, from http://www.ncbi.nlm.nih.gov/books/NBK2214/

The ground electrode can be positioned anywhere remote to the heart. The lead Y of the orthogonal lead system situates the positive electrode over the xiphoid (lowestest section of the breastplate) and the negative electrode inline with the skull at the front of the chest (Smith, 2014).

A single-lead recording system is usually sufficient in obtaining an ECG reading. To obtain the best recording using the three lead system "…the left arm electrode placed on the sternum, the right leg electrode on the right side in the fifth intercostal space at the level of the point of the shoulder, and the right arm electrode placed on the left side in the fifth intercostal space at the level of the point of the shoulder" (Smith, 2014, p.427). The electrodes used in this lead system are usually held in place using a tight surcingle when used for 24 hour Holter monitoring. Continuous Holter monitoring is useful when trying to monitor cardiac rhythms during exercise or arrhythmias that only occur intermittently. The lead system used within the smart textile device follows this three lead arrangement as discussed above.

3.3.5. Textile Substitute: The Heart Rate Monitor

Arduino is an open-source platform, used to build electronic projects using hardware and software applications. Arduino can be used to write and upload code to a physical programmable circuit board through software. Having gained basic knowledge throughout this project in the use of Arduino, by working alongside an Electronics Technician, a SparkFun heart rate monitor was an accessible used tool. The AD8232 Heart Rate Monitor was used to monitor the electrical activity of the heart which was charted as an ECG reading using Processing to create the visual data. This heart rate monitor uses the single lead system, consisting of three electrodes, Black (Right Arm), Blue (Left Arm) and Red (Right Leg).

Sketch, is a unit of code that is uploaded to the arduino and used to run the board. Using a sketch provided by SparkFun, the arduino can control and interact with the heart rate monitor.

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Figure 3.33. Lynch, E. (2013). [Anatomy of the horse]. Retrieved May 30, 2016, from http://laughingsquid.com/horses-inside-out-service-paints-anatomy-on-live-horses-to-educate-people-who-work-with-horses/.

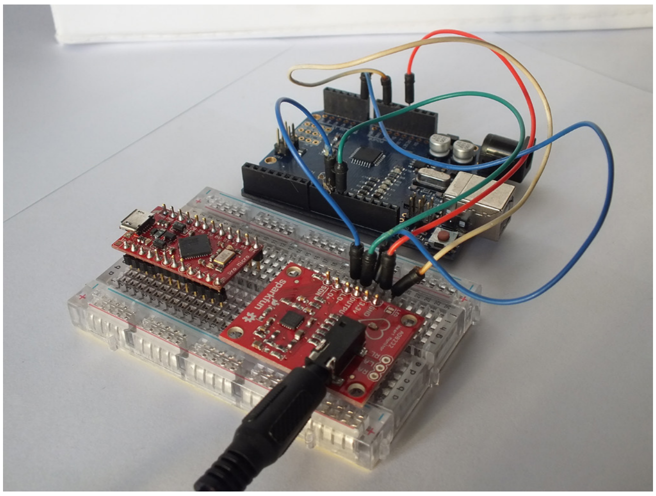

Figure 3.34. Fisher, H. (2016). Electronic setup.

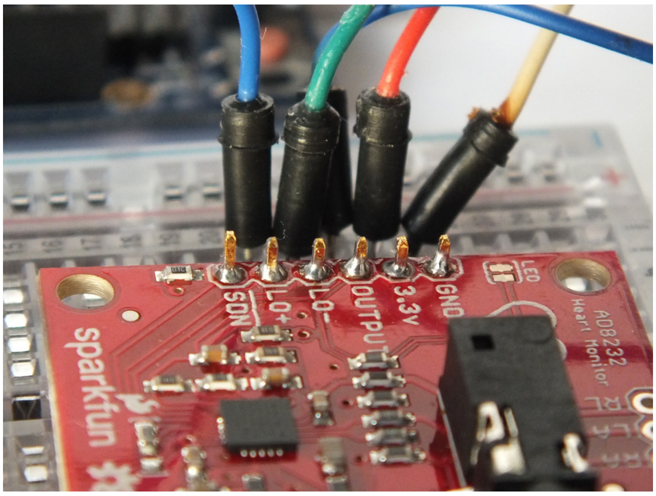

Figure 3.35. Fisher, H. (2016). Pins used on Sparkfun heart rate monitor.

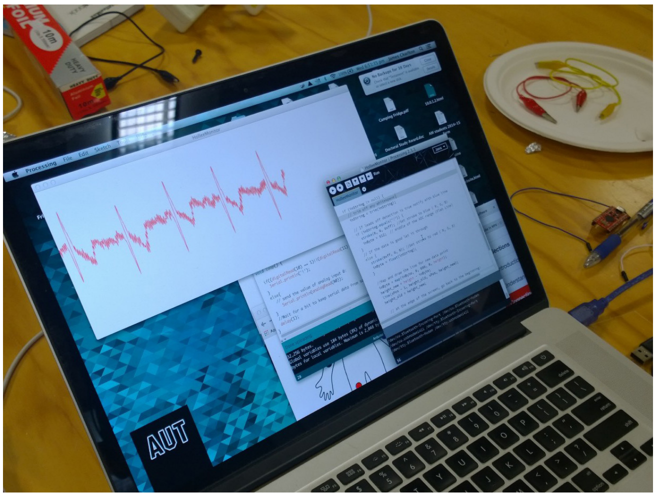

Figure 3.36. Fisher, H. (2016). ECG visualisation.

As an initial proof of concept an arduino UNO was used in which 5 pins were connected via a breadboard to the arduino using jumpers (also known as shunts) to create an electrical signal between the two boards. The five pins that were needed from the heart rate monitor were GND, 3.3v, output, LO- and LO+ which provided the function of ground, power supply, output signal and lead-off for both positive and negative. These pins were then connected to the arduino using pins GND, 3.3v, AO, 11 and 10 as advised by the SparkFun Hook Up Guide (SparkFun, n.d.). The data gathered by the heart rate monitor via the electrodes was inputted into the computer where the Processing sketch acted as an output visualising the ECG rhythm.

Traditional electrodes were used to set up the heart rate monitor prior to swapping to the use of the textile electrodes. To provide power to the electronics and an easy input access to the computer for data collection, the electronics were still connected to the computer via a USB cable. The textile electrodes were positioned on the horse and held in place using an elastic strap, to allow for accessible re-positioning of the electrodes. The electrical readings achieved during this first trial clearly indicated the possibility to obtain an ECG reading on a horse through the use of smart textile electrodes.

The development process of textile based electrodes which evolved from the investigation into knitted structures, confirmed that these sensing structures can be substituted for traditional electrodes. The developed textile electrode have verified, through a range of iterations, that an ECG reading from a horse can be detected when highly conductive yarns and stable structures are used. The essential requirements for a strong and accurate reading are dependent on the integration strategies and characteristics of the overall product.

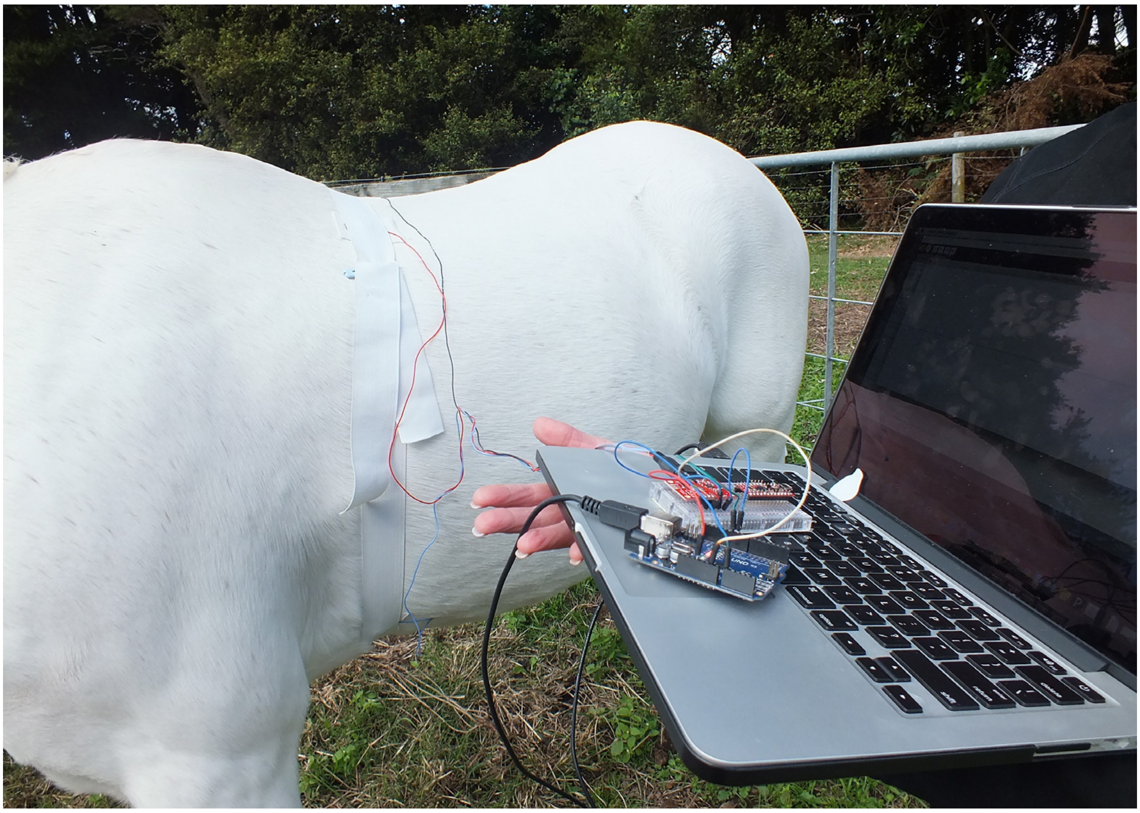

Figure 3.37. Fisher, H. (2016). ECG monitoring prototype on horse.

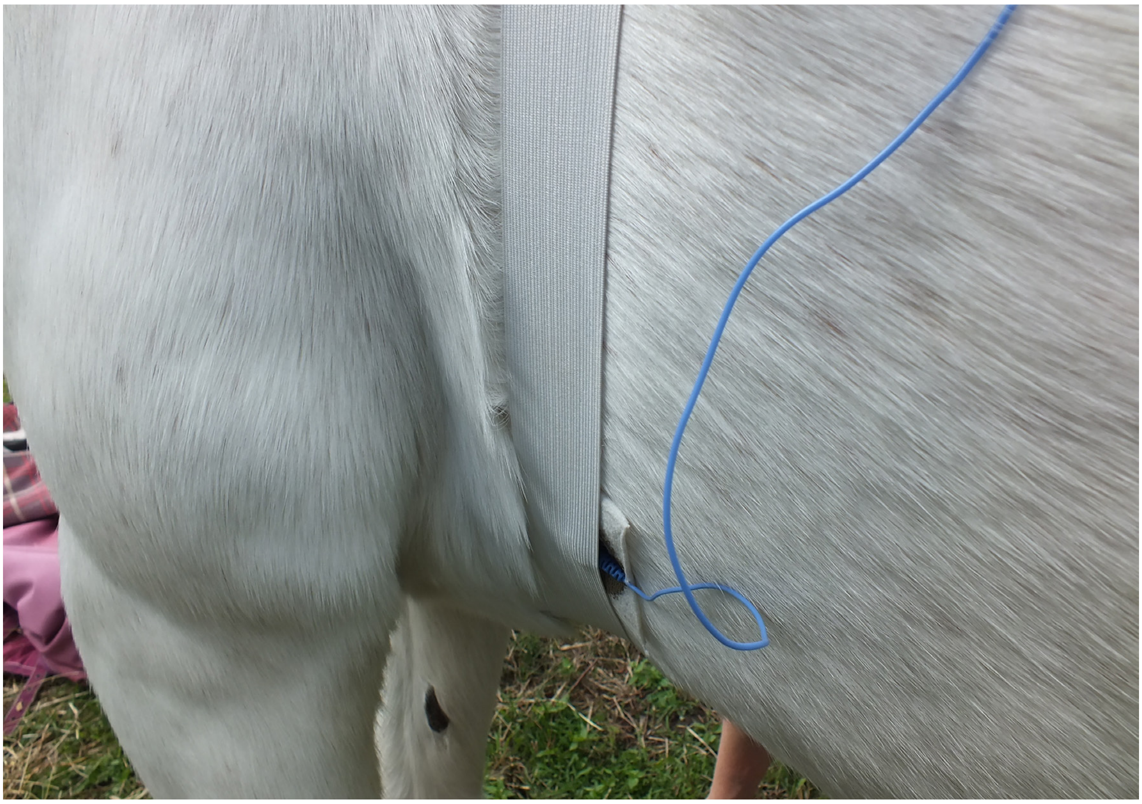

Figure 3.38. Fisher, H. (2016). Left arm electrode.

3.3.6. Shaping Changes

Iterative stages of product design development began after accomplishing the correct position of the textile electrodes and confirming their monitoring ability. A re-design stage followed the development of breastplate prototype one and two, leading to the refinement and design of the first shoulder guard prototype. Basing the design of this product around the shape of a conventional shoulder guard product, a pattern was developed and trialed on the horse where integration strategies and product characteristics where highlighted.

The initial shoulder guard prototype pattern underwent iterative re-adjustment cycles to accommodate correct sizing and shaping of the design. The adjusted pattern was 'drawn' into Shima Seiki KnitPaint using the Free Style option allowing the prototyped pieces to be shaped during the knitting process.

Figure 3.39. Fisher, H. (2016). Shoulder guard prototype one.

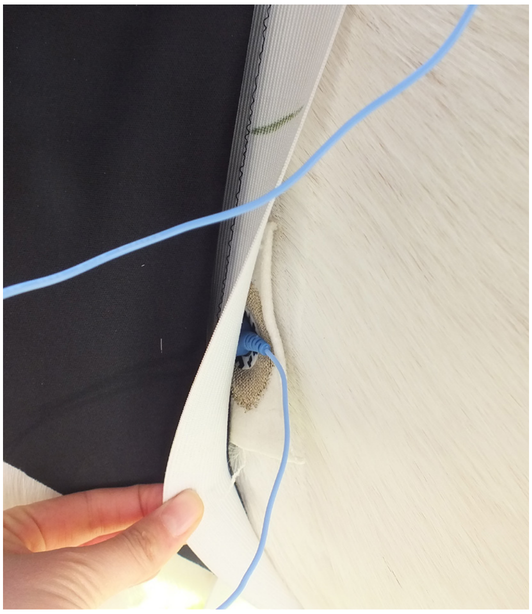

Figure 3.40. Fisher, H. (2016). Left side of sternum electrode placement.

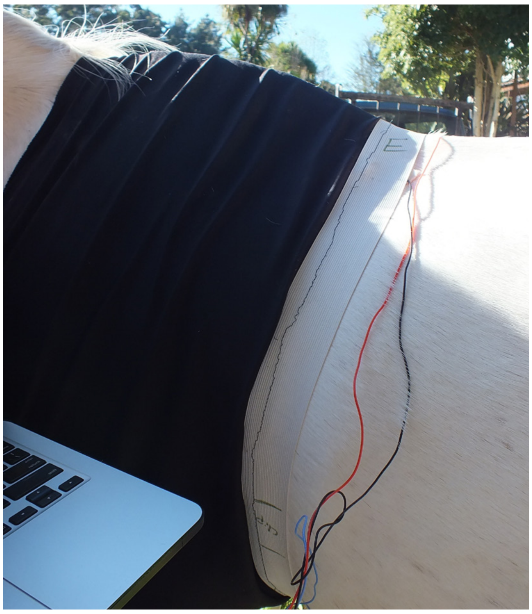

Figure 3.41. Fisher, H. (2016). Electrode placement on prototype.

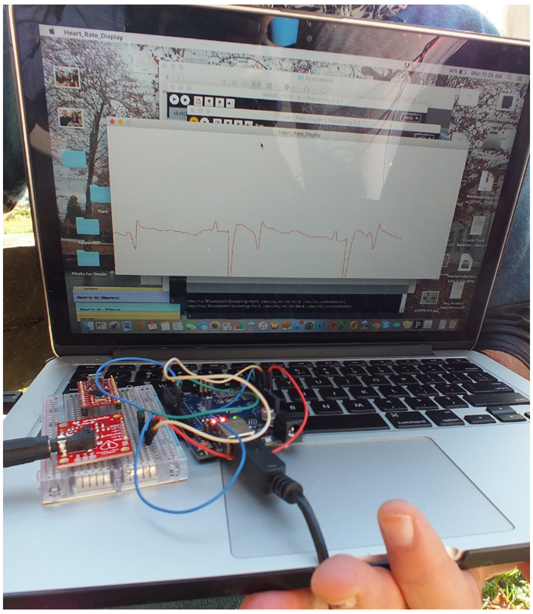

Figure 3.42. Fisher, H. (2016). Monitoring of heart rate during prototype trials.

Figure 3.43. Fisher, H. (2016). Pattern adjustment of prototype one.

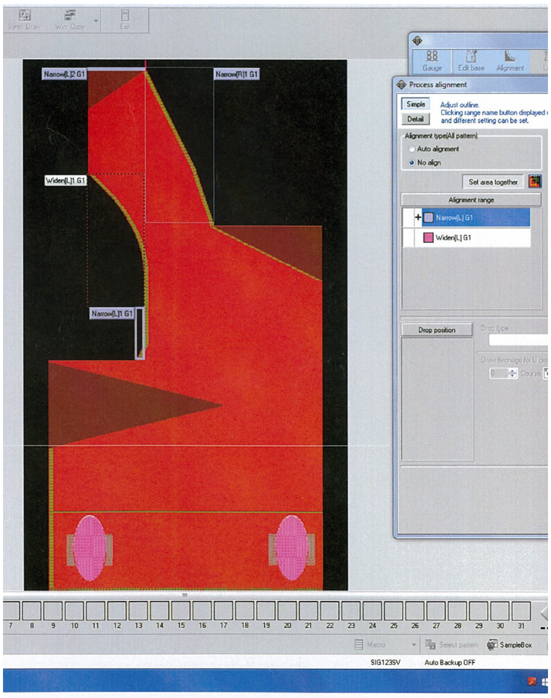

Figure 3.44. Fisher, H. (2016). Shaping of equipment pieces in KnitPaint.

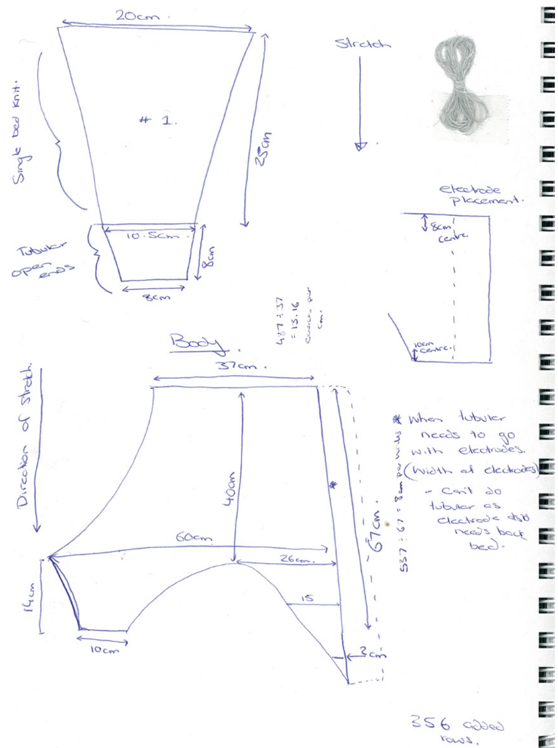

Figure 3.45. Fisher, H. (2016). Drawings and workings of new patterns.

Figure 3.46. Fisher, H. (2016). Shoulder guard prototype two, side view.

During the programming of the pattern pieces the electrodes were integrated seamlessly into the base fabric in the correct positions needed to detect and monitor the heart rate. The design and size of the shaped knitted equipment pieces underwent multiple iterations of re-programming and knitting.

Figure 3.47. Fisher, H. (2016). Integrated left side electrode.

The latest version of 'Tech Tack' is successful in monitoring the heart rate of horses through the integration of textile electrodes within a knitted piece of horse equipment. The final shaping of this product correctly accommodated the positions of the electrodes, achieving a fit and size of the product that complimented the textile electrodes and the needs of the horse.

Figure 3.48. Fisher, H. (2016). Right and left shoulder textile electrodes.

Further development of the 'Tech Tack' prototype will investigate advanced noise reduction techniques during heart rate monitoring caused by the movement of the horse. Trialling wireless and bluetooth technology will be an important next step in the development of long range monitoring, especially when continuous monitoring is required with the possibility of analysing the heart rate via a laptop or cellphone.

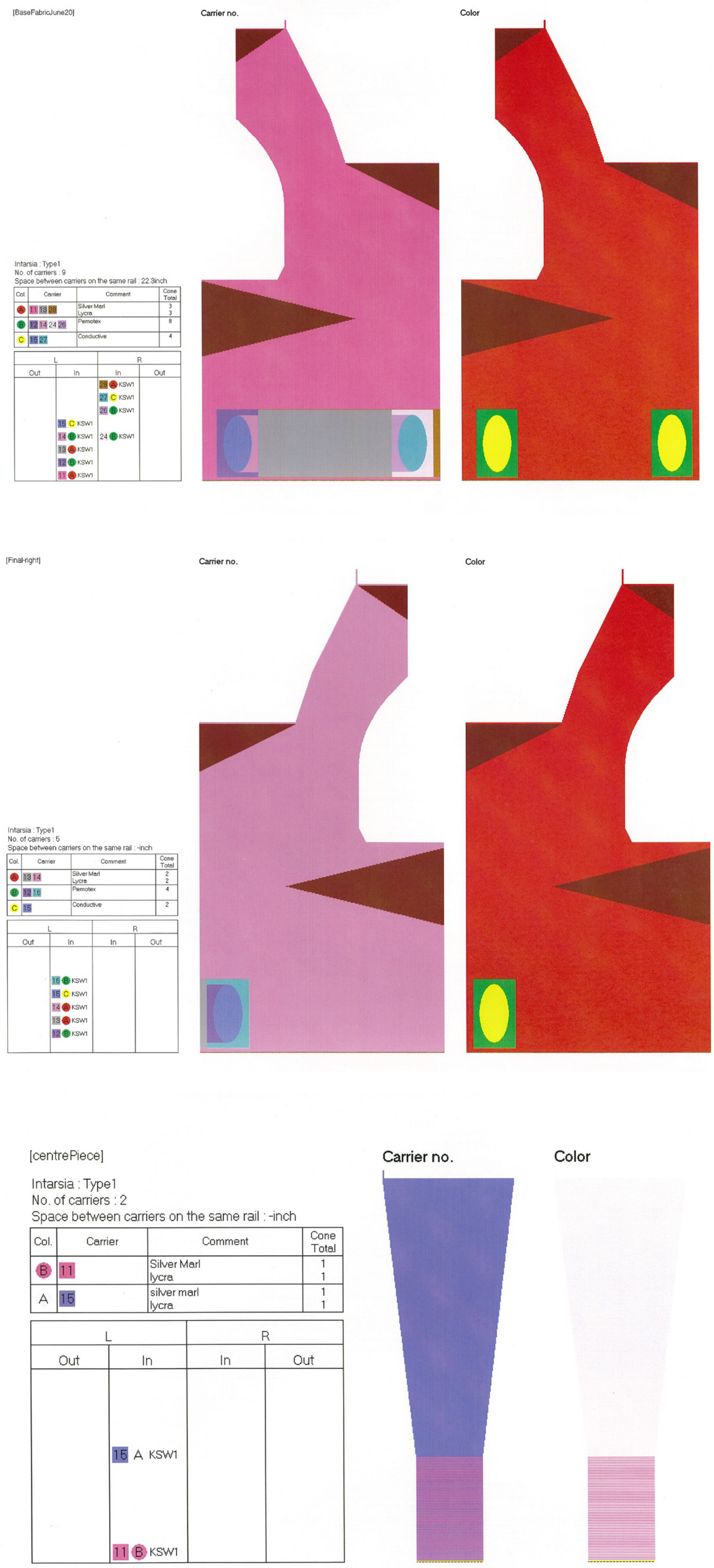

Figure 3.49. Fisher, H. (2016). Final shaped pattern pieces, KnitPaint.

Figure 3.50. Fisher, H. (2016). Integrated electrodes and felted pad.

Figure 3.51. Fisher, H. (2016). Side view of final prototype, TechTack.

CONCLUSION

"Design is the ability to imagine that-which-does-not-yet-exist, to make it appear in concrete form as a new, purposeful addition to the real world"

(Nelson & Stolterman, 2003, p.9).

CONCLUSION

As a designer this research provided the opportunity to challenge barriers between technological parameters and the tactile qualities of a traditional textile that of knitted fabric. An understanding between the structural composition of knit and the technical performance of yarns provided a platform for the construction of the textile sensors. Working within an interdisciplinary field created a balance between an aesthetically designed device that incorporated all the essential electronic properties by embracing the physical attributes of the knitted textile. The intrinsic integration of highly conductive yarn, identified during testing, into a stable knit structure helped create the basis for the textile electrode. The versatility of knit accommodated the reliability of the textile electrodes by achieving a form fitting piece of equipment that has minimal movement, reducing noise within the heart rate reading; therefore increasing its monitoring accuracy. Correct positioning of the integrated electrodes within the knitted piece of equipment allowed 'Tech Tack' repeatability of monitoring and produce a visual ECG reading each and every time the device was worn.

Contribution to New Knowledge

This practice based research highlighted design as a method for the creation of objects and artefacts acting as a change agent through inquiry and action, generating and enabling new ways of thinking and thus change. This design based project makes contributions to new knowledge in the areas of textile design, healthcare and the equine industry. The most significant contribution of this research is the development of a prototype and an integrated smart textile system which highlights the innovative journey and the iterative nature of this research process. While the sensor development was a key part of this project, an equally important aspect was the exploration of textiles and their material properties. The yarns and fibres were chosen based on their tactile qualities as well as technical performance. This research expands the use of smart textiles into new areas of investigation by revealing their potential for use within animal care. The working prototype, 'Tech Tack', provides confirmation of new possibilities through the integration and adaption of smart textiles and sensoring technology into the production of an equine based product.

Importantly, this research provides designers and researchers with accessible and interchangeable new knowledge which can be utilised by many disciplines. Discoveries through this research have revealed technical and practical knowledge about the construction of textile based sensors. Through the analysis of fabrication techniques such as knitting and felting, the influential functions which conductive yarns and fibres can have on structural textile sensors has been revealed, these findings are useful across many multi/interdisciplinary platforms working within smart textile resolution of product integration. The documentation of this research through the written exegesis, research notes and 'A Conductive Knit Structure Investigation' makes these findings readily available to designers and researchers within this field along with both students and the public through the Textile and Design Lab at Auckland University of Technology (AUT) and via the university online portals.

Future Research Possibilities

The functionality and versatility of knit has opened up areas into which further research could be developed. This research focuses on the knitting of ECG electrodes, where it is clear that the Shima Seiki knitting machine computer interface suggests the possibility of a more seamless integration between textiles and electronics can be developed as a non-invasive method of monitoring.

Primarily, current research in the area of smart textile application has been focused on human based applications, however, this research has focused on the translation of this technology into animal care. Although this research examined only one aspect of integrating smart textiles within animal care, it has developed a knowledge base that can now be applied and translated to multiple areas of future applications in both animal and human care. The final developed prototype 'Tech Tack' presents the opportunity to expand its current use into other areas of physiological monitoring with the potential to become a continuous long range smart textile monitoring system. With the adoption of this technology by trainers and veterinarians further development of these findings could lead to the refinement of this prototype with clear benefits as a potential smart textile product for the equine industry.

THE EXHIBITION

THE EXHIBITION

Prototype and Development Display

The display was curated to show the development process of the textile sensors and the final prototype 'Tech Tack', presenting the research practice as part of the thesis examination. The finished prototype was also showcased at the exhibition. Physical samples and interactive sensors were accompanied by a short film of the final prototype being applied and worn by a horse. The following images illustrate all aspects of the practice shown at the examination exhibition.

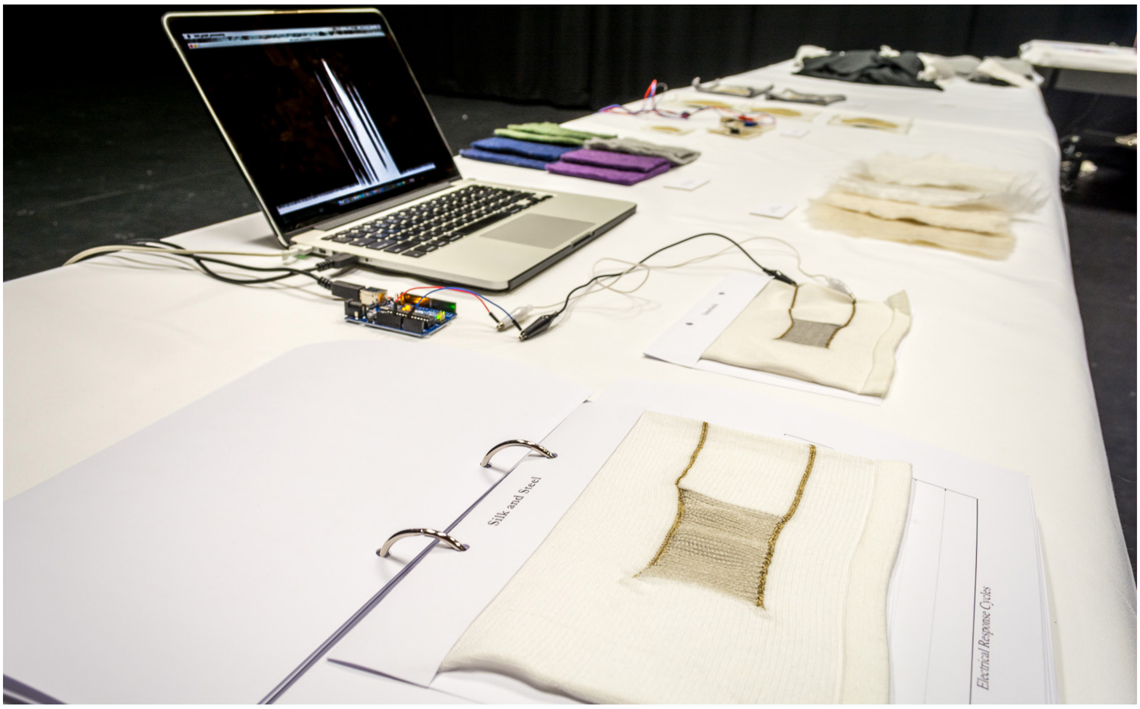

Figure 4.1. Marks, S. (2016). 'A Conductive Knit Structure Investigation' book with interactive sensor and graph display.

Figure 4.2. Marks, S. (2016). Natural and re-generated felted fibres.

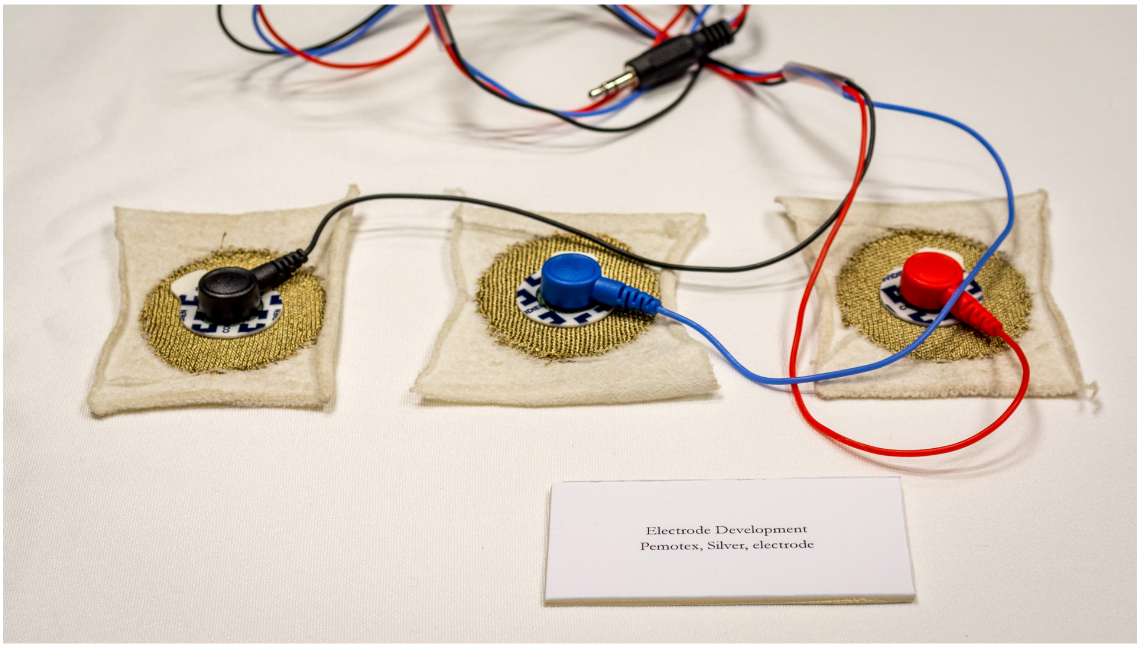

Figure 4.3. Marks, S. (2016). Initial textile electrodes and hardware attachment.

Figure 4.4. Marks, S. (2016). Prototype two with marked adjustments.

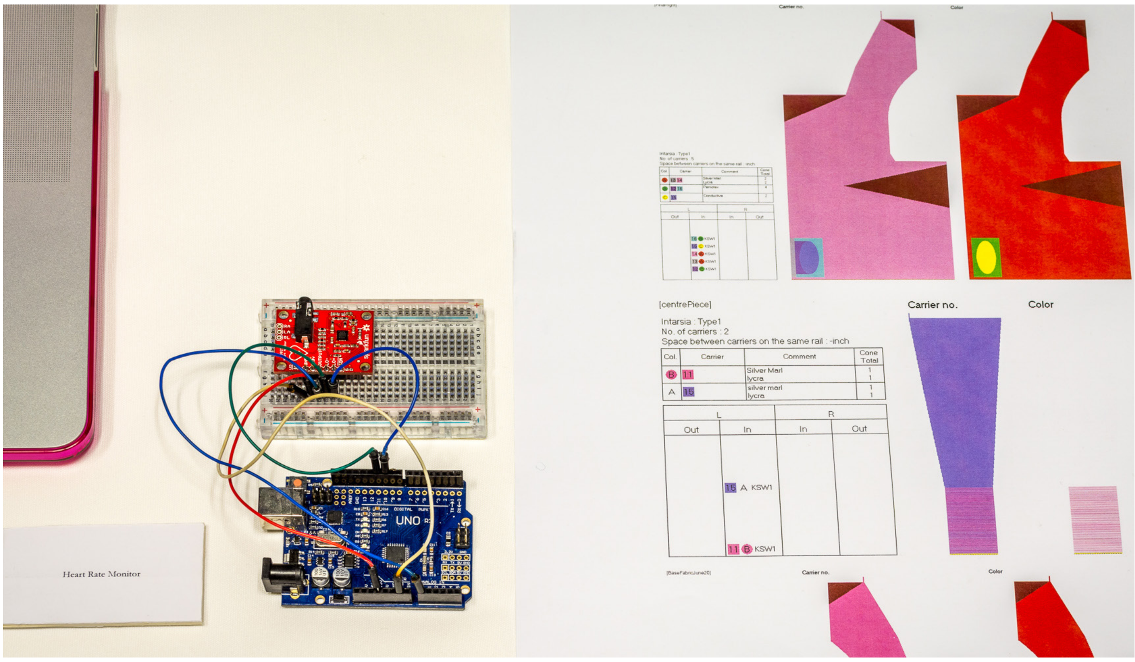

Figure 4.5. Marks, S. (2016). Heart rate monitor electronics and shaped product pieces.

Figure 4.6. Marks, S. (2016). Inside view of 'Tech Tack' electrodes.

Figure 4.7. Marks, S. (2016). Final prototype 'Tech Tack'.

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GLOSSARY OF TERMS

Ardunio: an open-source platform, used to build electronic projects using hardware and software applications

Base package: Shima Seiki term - represents stitch composition within a line of code where registered numbers refers to the construction of the design.

Cardiac arrhythmia: irregular heartbeat

Composite fabric: a fabric composed of two or more distinctly different material.

Course: horizontal row of knitted stitches/loops

Double Knit: produced on a double bed machine where two yarn feeders are required.

Electrocardiogram (ECG): recording of the electrical activity of the heart

Fabrics: general textile term referring to structured materials made from fibres and/or yarns.

Feeders/carriers: guide and feed the yarn into the needle hook.

Impedance (Z): the measure of resistance that a circuit presents to a current when a voltage is applied

Miss stitch (miss knit): where one or more needles do not form a stitch.

Plating: knit technique that feeds two yarns to each needle resulting in a different texture or colour on either side.

Programming: inputting design or technical information into a computer program in a language the program/ machine understands.

Prototype: initial ideas trialed prior to developing a more refined design.

Resistance: electrical quantity of a material's opposition to the flow to electrical current

Rib: fabric made up of stitches where alternative wale stitches are knitted on the front and back bed.

Single Knit: simplest knitted weft structure which is produced on a single bed.

Smart textiles: materials or fabrics that contain the ability to sense environmental stimuli and respond.

Stitch structure: formation of knitted stitches used to create the fabric.

'Tech Tack': prototype which explores the integration of sensing and monitoring technology within equine-based equipment.

Textile/s: applies to products that are constructed from fibres and yarns.

Tuck: an enlarged loop formed when the previous stitch is not cast off.

Wale: vertical column of knitted stitches/ loops.

Yarns: continuous strand of fibre, either filament or staple.

APPENDICES

Appendix A

Equine Rug Mind Map

An investigation into equine rugs provided an understanding of materials, fastenings/strapping, style and shape of the equipment and extra features. As each rug has a specific use, this investigation helped me understand what was required in terms of fibre and material choice when designing Tech Tack as an outdoor/indoor product.

Information was gathered and compiled from the following sources:

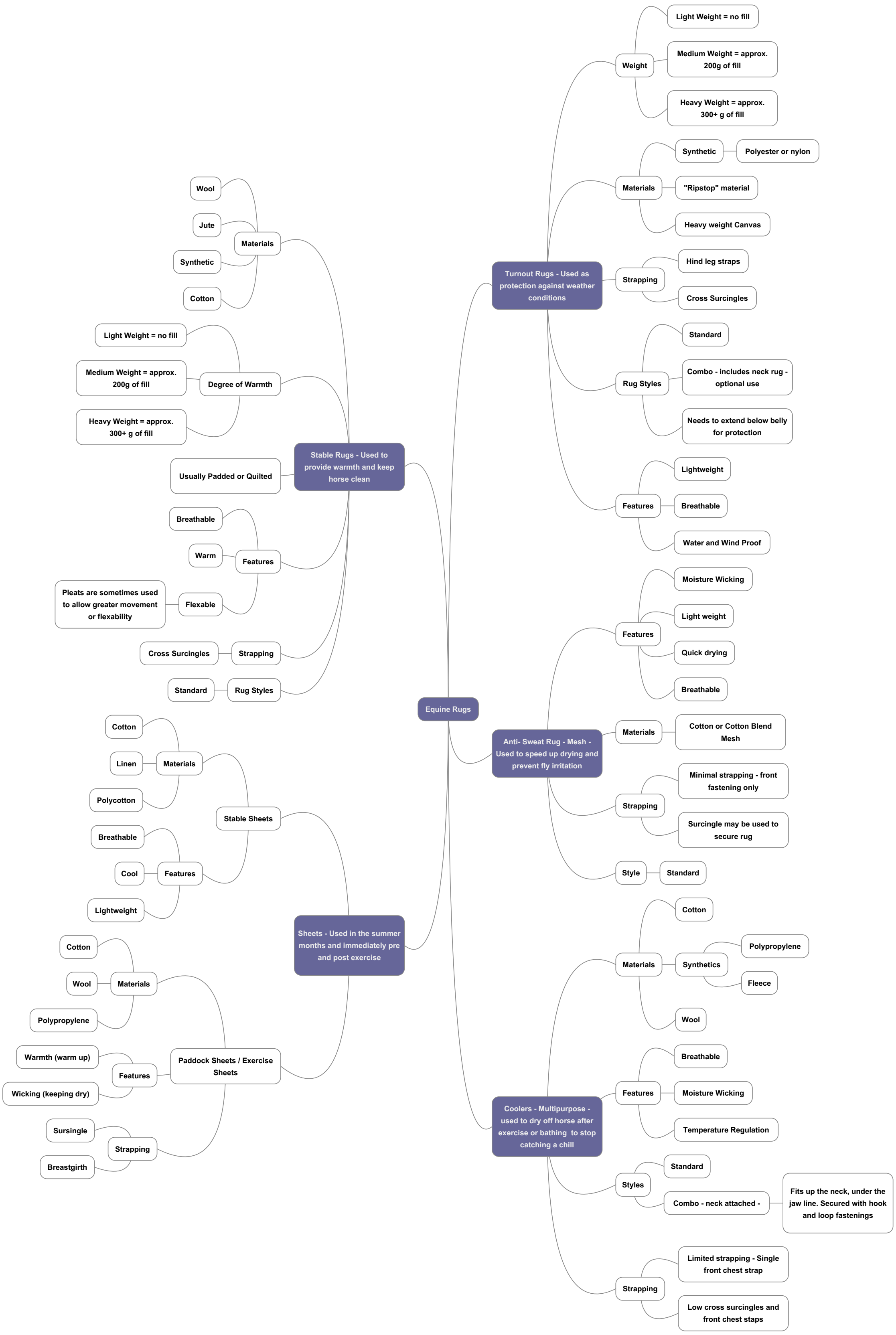
Muir, S., & Sly, D. (2001). The complete horse & rider: A practical handbook of riding and an illustrated guide to tack and equipment. London: Anness.

Horse Channel. (2011). Field guide to horse blanket styles. Retrieved November 7, 2015, from http://www.horsechannel.com/horse-keeping/horse-blanket-styles.aspx

Equestrian and Horse. (n.d.). Horse Rugs. Retrieved November 7, 2015, from http://www.equestrianandhorse.com/tack/rugs/introduction.html

Equine World UK. (n.d.). Types of horse rugs. Retrieved November 7, 2015, from http://www.equine-world.co.uk/horses_care/types_horse_rugs.asp

Appendix A



Equine Rugs
Stable Rugs - Used to provide warmth and keep horse clean
Materials
Wool
Jute
Synthetic
Cotton
Degree of Warmth
Light Weight = no fill
Medium Weight = approx. 200g of fill
Heavy Weight = approx. 300+ g of fill
Usually Padded or Quilted
Features
Breathable
Warm
Flexable
Pleats are sometimes used to allow greater movement or flexability
Strapping
Cross Surcingles
Rug Styles
Standard
Turnout Rugs - Used as protection against weather conditions
Weight
Light Weight = no fill
Medium Weight = approx. 200g of fill
Heavy Weight = approx. 300+ g of fill
Materials
Synthetic
Polyester or nylon
"Ripstop" material
Heavy weight Canvas
Strapping
Hind leg straps
Cross Surcingles
Rug Styles
Standard
Combo - includes neck rug - optional use
Needs to extend below belly for protection
Features
Lightweight
Breathable
Water and Wind Proof
Anti- Sweat Rug - Mesh - Used to speed up drying and prevent fly irritation
Features
Moisture Wicking
Light weight
Quick drying
Breathable
Materials
Cotton or Cotton Blend Mesh
Strapping
Minimal strapping - front fastening only
Surcingle may be used to secure rug
Style
Standard
Sheets - Used in the summer months and immediately pre and post exercise
Stable Sheets
Materials
Cotton
Linen
Polycotton
Features
Breathable
Cool
Lightweight
Paddock Sheets / Exercise Sheets
Materials
Cotton
Wool
Polypropylene
Features
Warmth (warm up)
Wicking (keeping dry)
Strapping
Sursingle
Breastgirth
Coolers - Multipurpose - used to dry off horse after exercise or bathing to stop catching a chill
Materials
Cotton
Synthetics
Polypropylene
Fleece
Wool
Features
Breathable
Moisture Wicking
Temperature Regulation
Styles
Standard
Combo - neck attached -
Fits up the neck, under the jaw line. Secured with hook and loop fastenings
Strapping
Limited strapping - Single front chest strap
Low cross surcingles and front chest staps

Appendix B

Smart Textile System Mind Map

As knowledge was gained in the area of smart textiles, a mind map was formed to help understand the relationship between the components and how each aspect worked. This mind map was a way to systematically present the information visually.

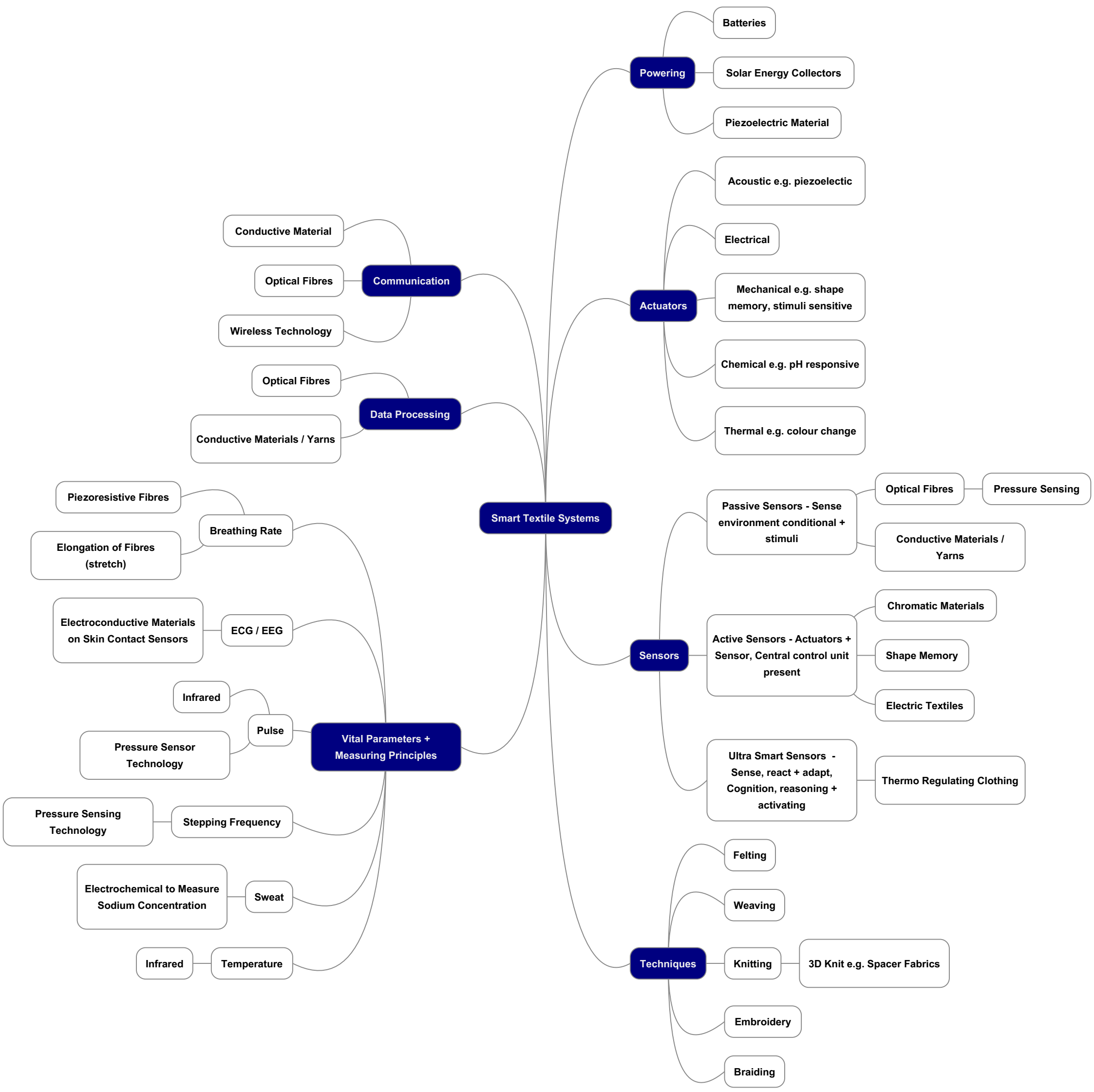
Information was gathered and compiled from the following sources:

Schwarz, A., Langenhove, L. V., Guermonprez, P., & Deguillemont, D. (2010, June). A roadmap on smart textiles. Textile Progress, 42(2), 99-180. doi:10.1080/00405160903465220

Stoppa, M., & Chiolerio, A. (2014). Wearable Electronics and Smart Textiles: A Critical Review. Sensors, 14(7), 11957-11992. doi:10.3390/s140711957

Castano, L., & Flatau, A. (2014). Smart fabric sensors and e-textile technologies: A review. Smart Mater. Struct. Smart Materials and Structures, 23(5), 1-25. doi:10.1088/0964-1726/23/5/053001

Appendix B



Smart Textile Systems
Powering
Batteries
Solar Energy Collectors
Piezoelectric Material
Actuators
Acoustic e.g. piezoelectic
Electrical
Mechanical e.g. shape memory, stimuli sensitive
Chemical e.g. pH responsive
Thermal e.g. colour change
Sensors
Passive Sensors - Sense environment conditional + stimuli
Optical Fibres
Pressure Sensing
Conductive Materials / Yarns
Active Sensors - Actuators + Sensor, Central control unit present
Chromatic Materials
Shape Memory
Electric Textiles
Ultra Smart Sensors - Sense, react + adapt, Cognition, reasoning + activating
Thermo Regulating Clothing
Techniques
Felting
Weaving
Knitting
3D Knit e.g. Spacer Fabrics
Embroidery
Braiding
Communication
Conductive Material
Optical Fibres
Wireless Technology
Data Processing
Optical Fibres
Conductive Materials / Yarns
Vital Parameters + Measuring Principles
Breathing Rate
Piezoresistive Fibres
Elongation of Fibres (stretch)
ECG / EEG
Electroconductive Materials on Skin Contact Sensors
Pulse
Infrared
Pressure Sensor Technology
Stepping Frequency
Pressure Sensing Technology
Sweat
Electrochemical to Measure Sodium Concentration
Temperature
Infrared

Appendix C

Development of Felted Sensors and Testing

Weight (total) = 50g

Conductive (5%) = 2.5g

Wool (95%) = 47.5g

These measurements were halved and then hand carded into two A4 batts prior to being felted.

Each batt weighed = 25g

Wool weight = 23.75g

Conductive weight = 1.25g

The stainless steel conductive fibres used were in the form of a staple fibre.

Each colour, purple, blue, green and grey were a reference to the direction the conductive fibres had been layered in.

Purple: vertical

Blue: vertical (layer 1 & 3) then horizontal (layer 2 & 4).

Green: Diagonal

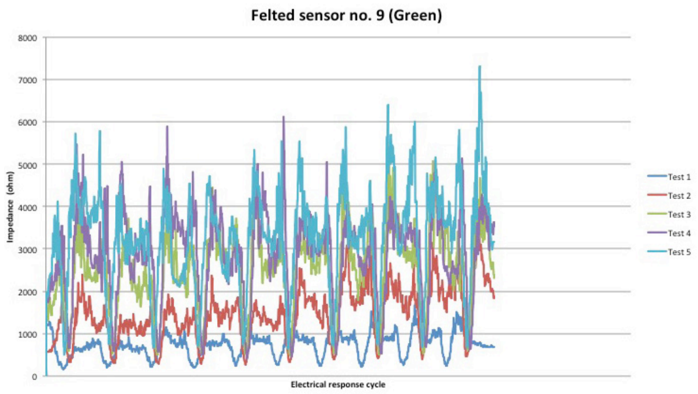
Grey: Hand carded, mixed through wool

Each batt contained four layers of wool and conductive which were divided by weight

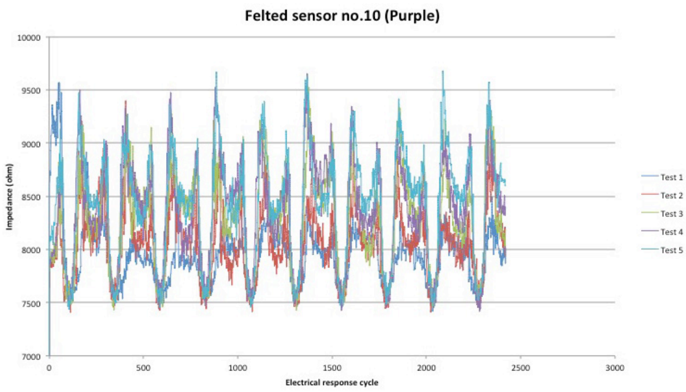
Layering of conductive fibres

Wool and conductive batts

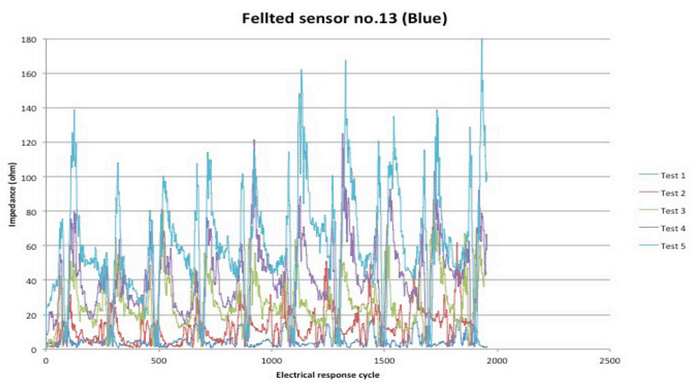
Appendix C


Felted sensor no. 9 (Green)
Impedance (ohm)
Electrical response cycle
Test 1
Test 2
Test 3
Test 4
Test 5

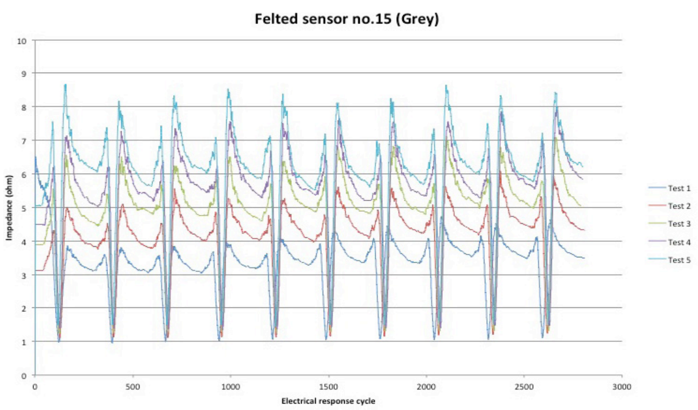

9


Felted sensor no.10 (Purple)
Impedance (ohm)
Electrical response cycle
Test 1
Test 2
Test 3
Test 4
Test 5


10


Fellted sensor no.13 (Blue)
Impedance (ohm)
Electrical response cycle
Test 1
Test 2
Test 3
Test 4
Test 5


13


Felted sensor no.15 (Grey)
Impedance (ohm)
Electrical response cycle
Test 1
Test 2
Test 3
Test 4
Test 5


15

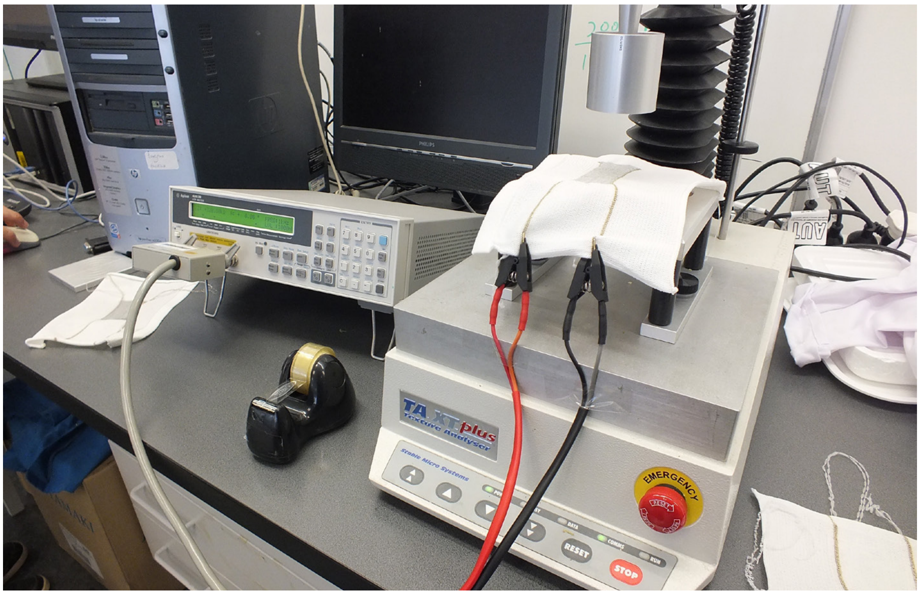
Appendix D

A Conductive Knit Structure Investigation

An investigation into conductive knitted structures. This sample book was an early collaborative project between Hollee Fisher and Caroline Stephen. The parameters were set by conductive yarn used, the size of the conductive patch in terms of courses and wales, and the surrounding based fabric. The variable of each sample was the knitted structure used for constructing the conductive area. Stitch structures which varied between a combination of purl, tucks and double knits were explored.

These conductive samples underwent testing to investigate the resistive capability of different stitch structures and their repeatability. This testing was carried out alongside Master of Engineering student Yasir Al-Hilali.

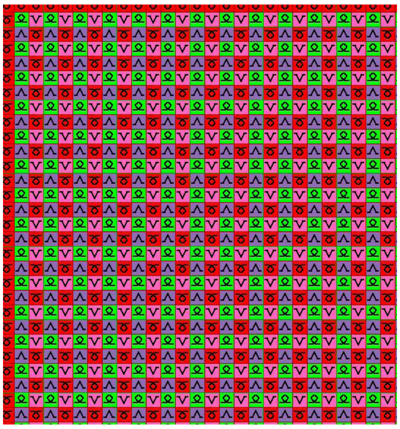
All technical knit structure visualisations in the following appendices have been generated via the Shima Seiki programming system, KnitPaint.

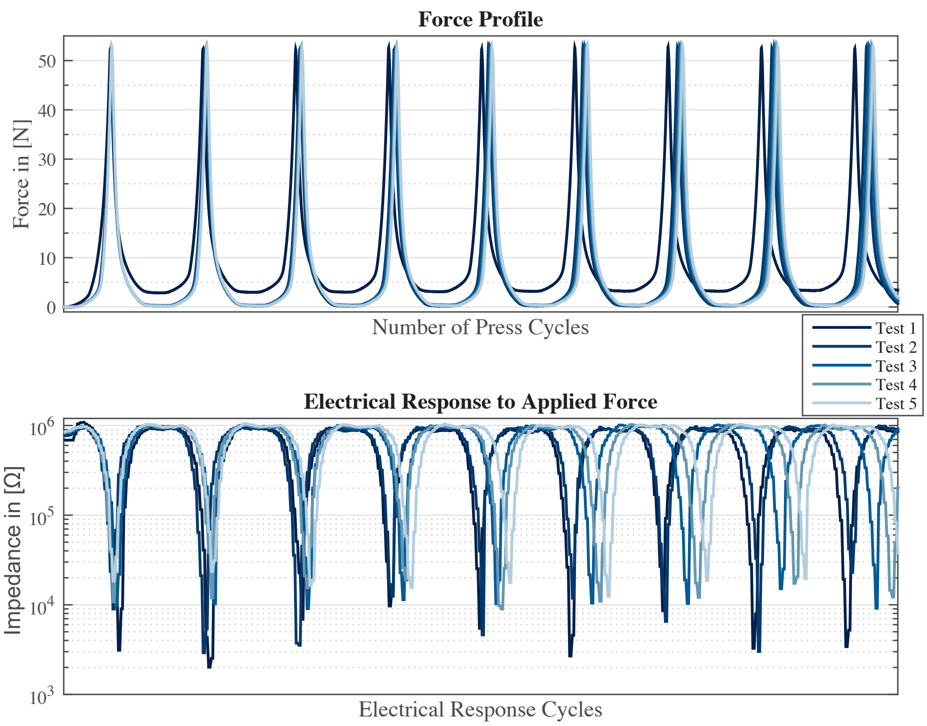


Sensor Testing Setup

Appendix D

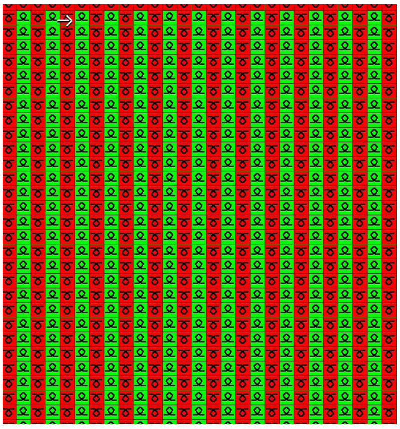
Stitch: Full Cardigan

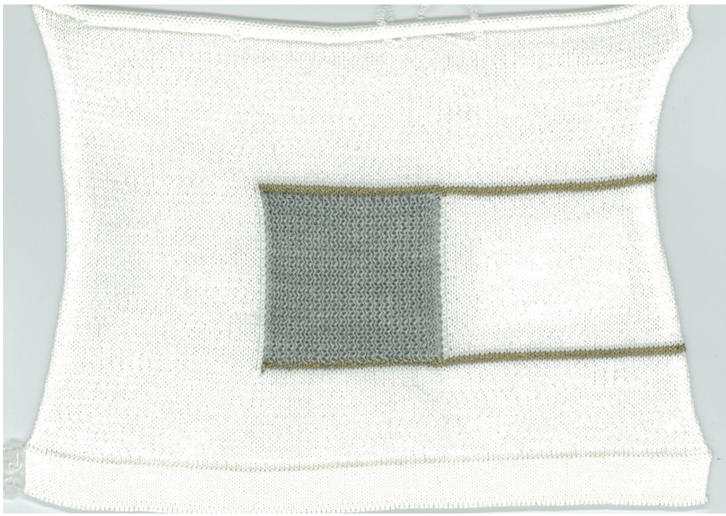


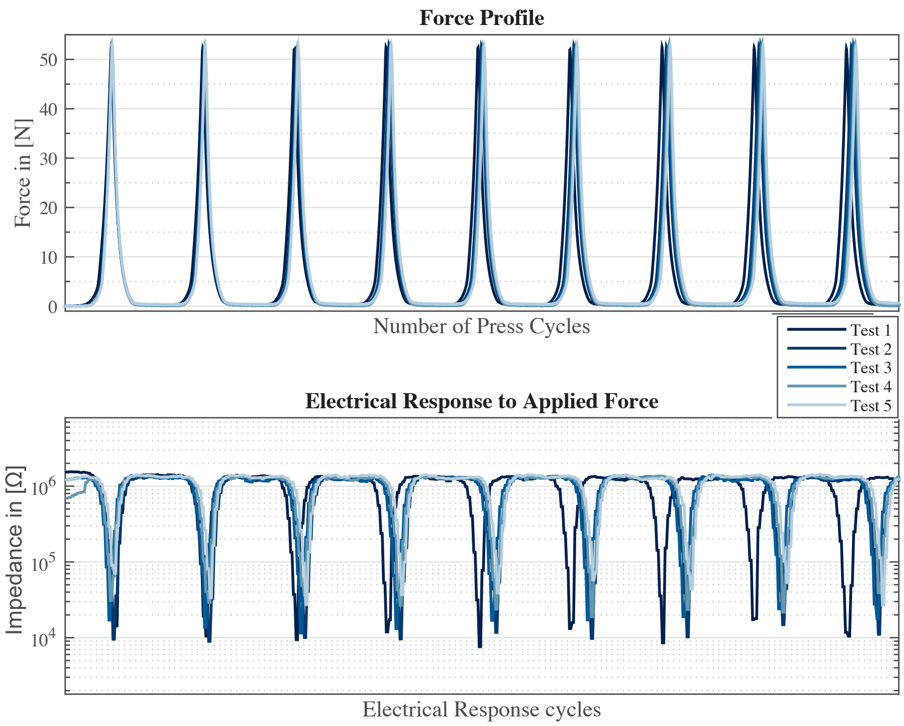


Appendix D

Stitch: 1x1 Rib

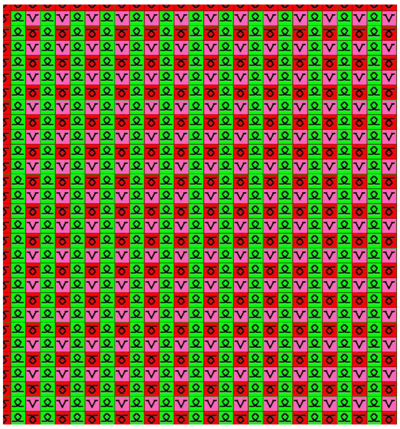


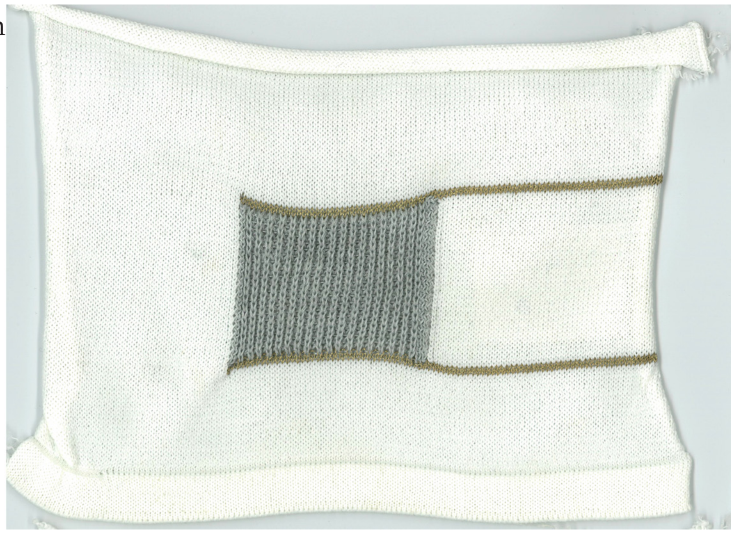


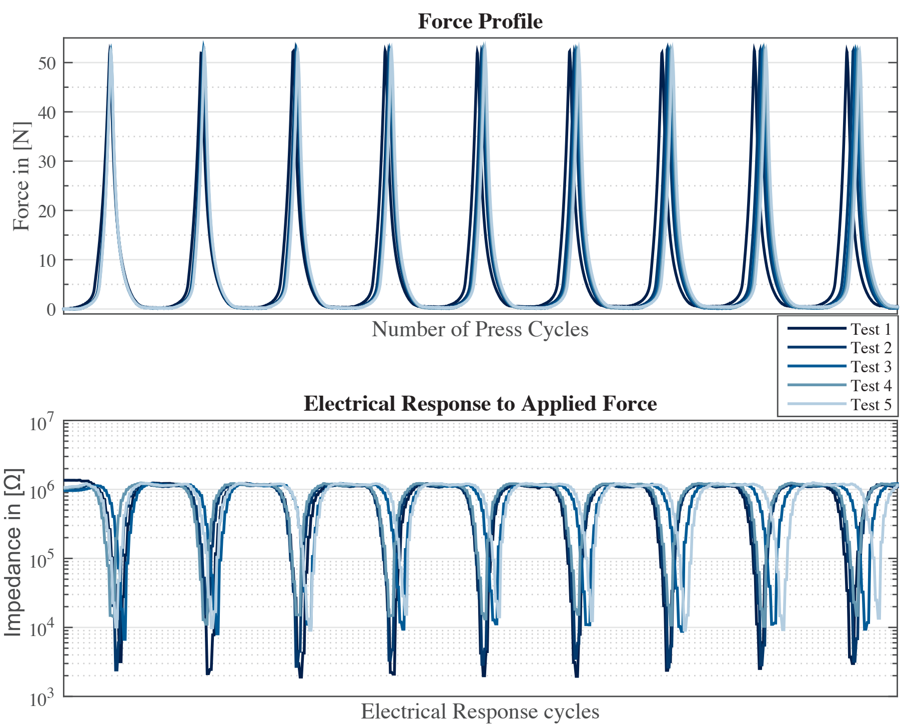


Appendix D

Stitch: Half Cardigan

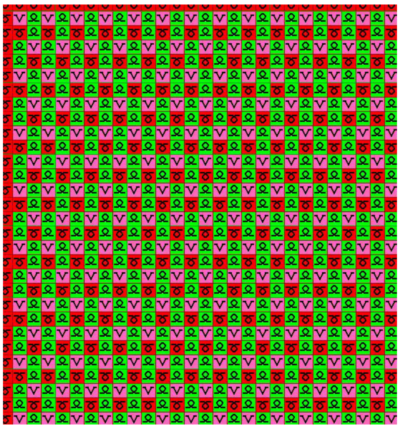


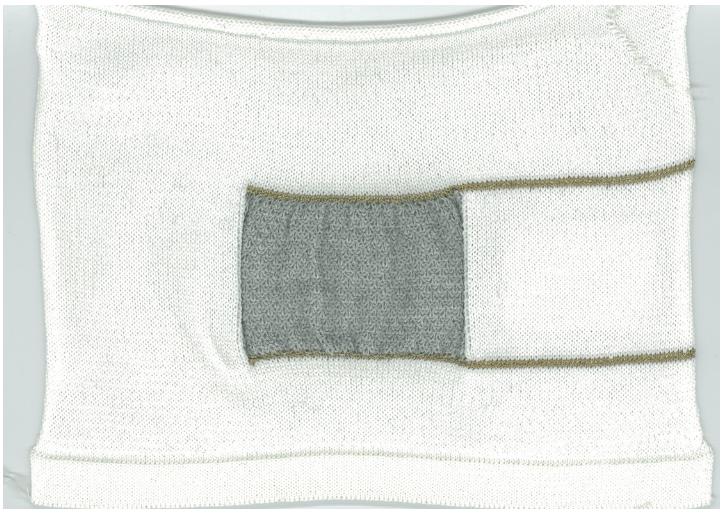


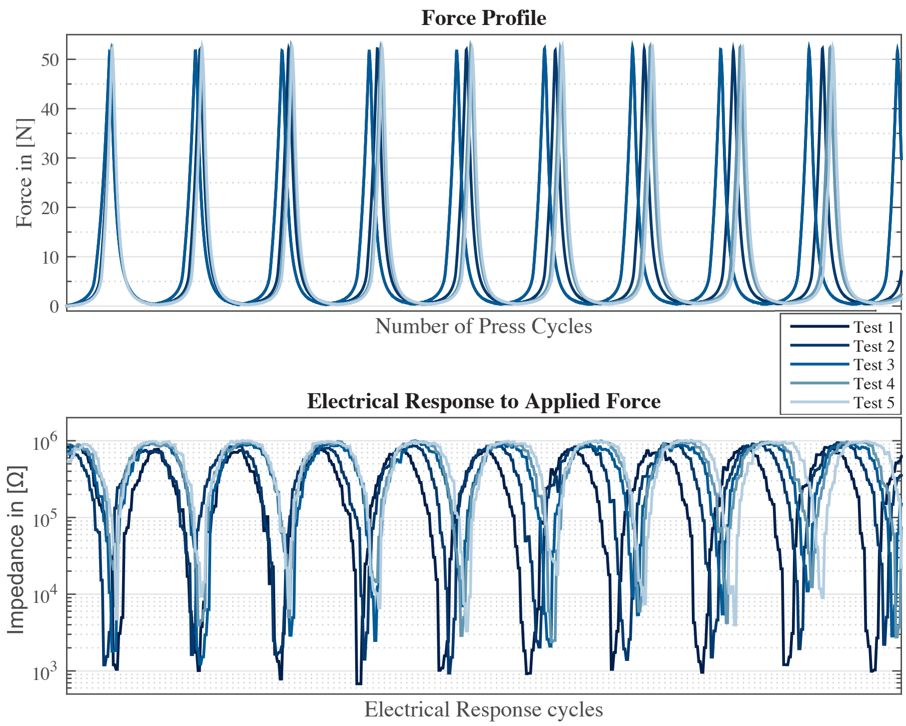


Appendix D

Stitch: Tuck v1

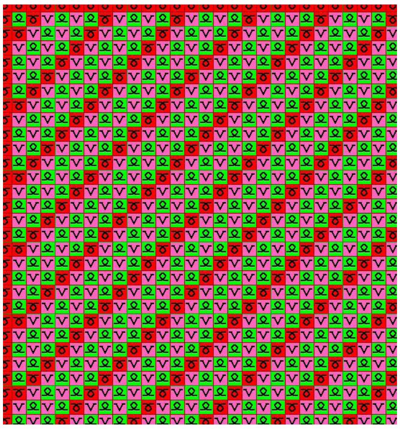


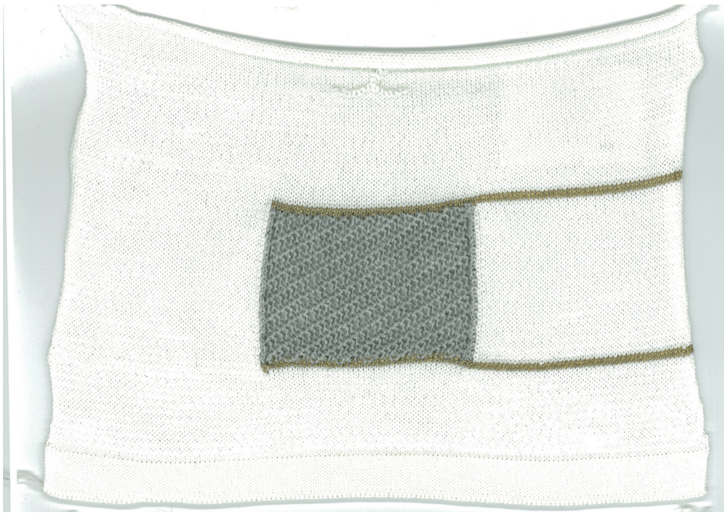


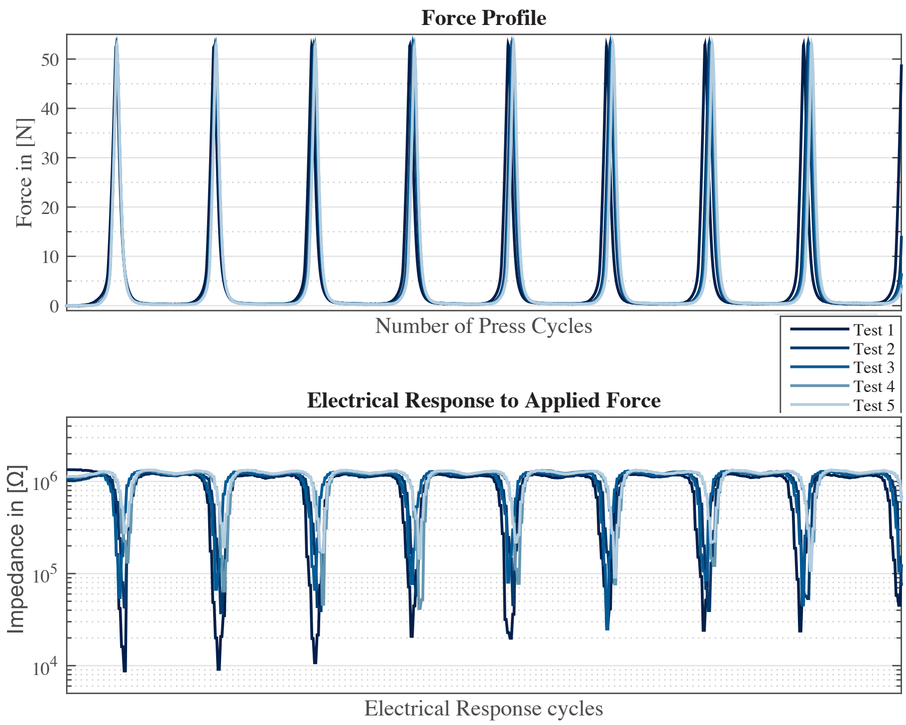


Appendix D

Stitch: Tuck v2

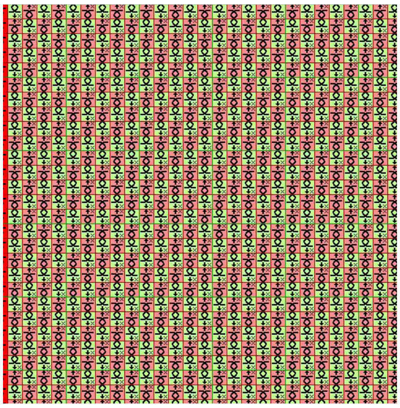


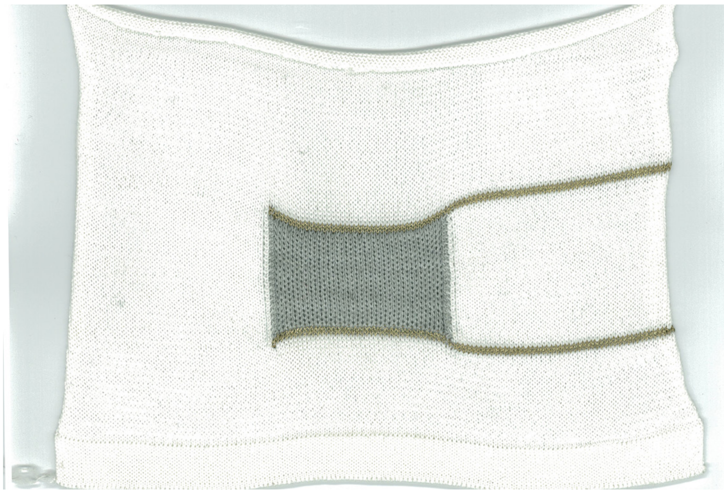


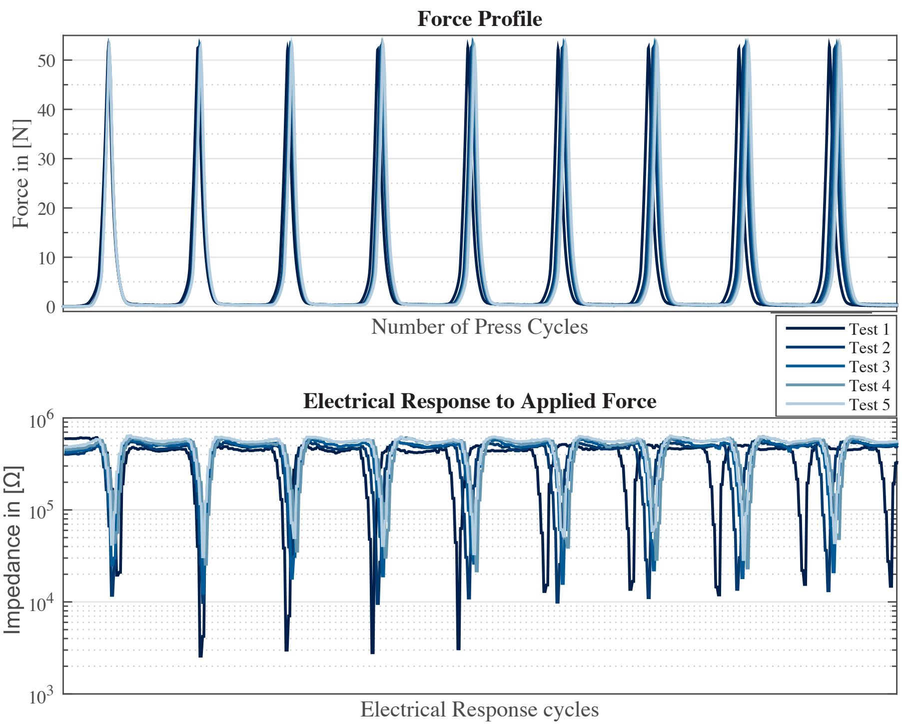


Appendix D

Stitch: Interlock





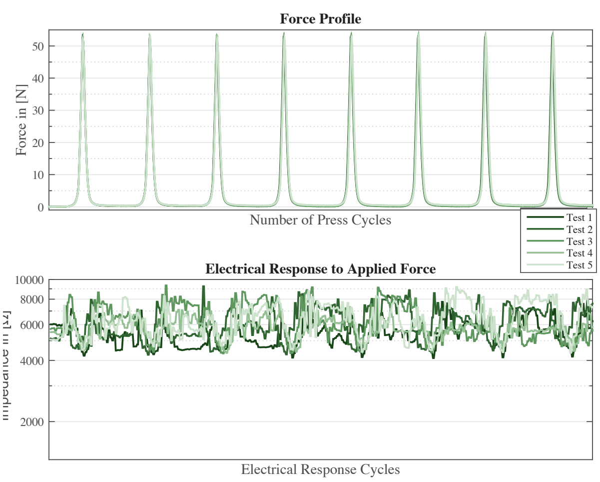


Appendix E

A Conductive Yarn Analysis Investigation

An investigation into conductive yarns. The parameters were set by the interlock structure, the size of the conductive patch in terms of courses and wales, and the surrounding based fabric. The variable of each sample was the conductive yarn used to construct the conductive area. The use of conductive yarns varied between a combination with polyester and merino wool yarns. The conductive yarns explored the use of a range of different metals.

These conductive samples underwent testing to investigate the resistive capability of different conductive yarns and their repeatability. This testing was carried out alongside Master of Engineering student Yasir Al-Hilali.



Company

The Yarn Purchasing Association

Name of Yarn

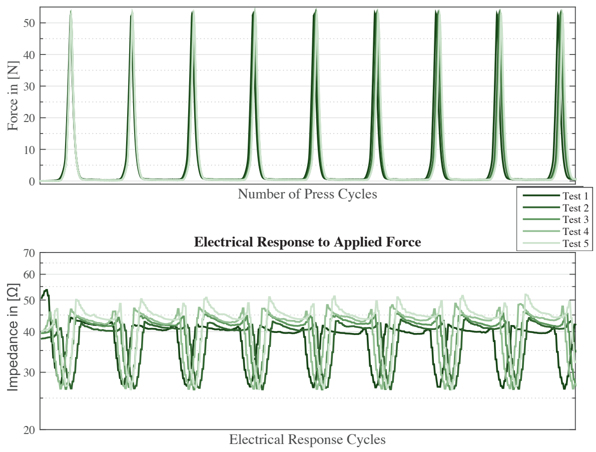
Silk and Steel

Yarn Composition

65% Silk 35% Stainless Steel

No. of ends

2 ends



Company

Swicofil

Name of Yarn

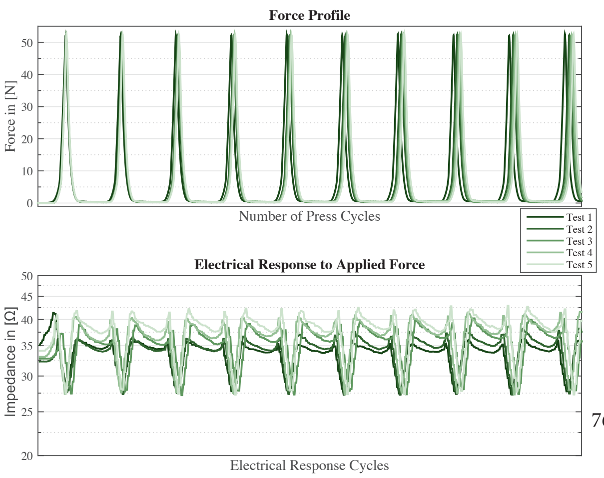
SwicoSilver

Yarn Composition

Plasma Silver coated Polyester

No. of ends

1 end SwicoSilver, 1 end polyester



Company

Swicofil

Name of Yarn

SwicoSilver

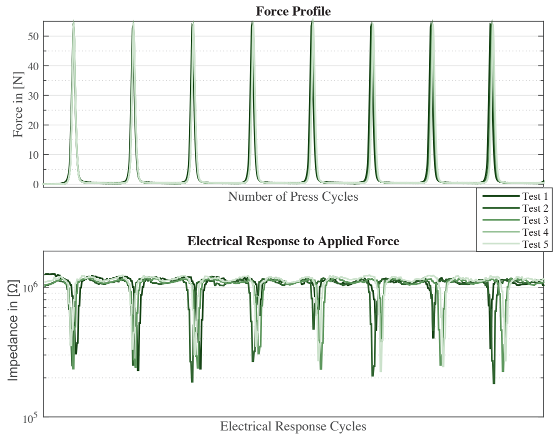
Yarn Composition

Plasma Silver coated Polyester

No. of ends

1 end SwicoSilver, 1 end merino wool

Appendix E



Company

Habu Textiles

Name of Yarn

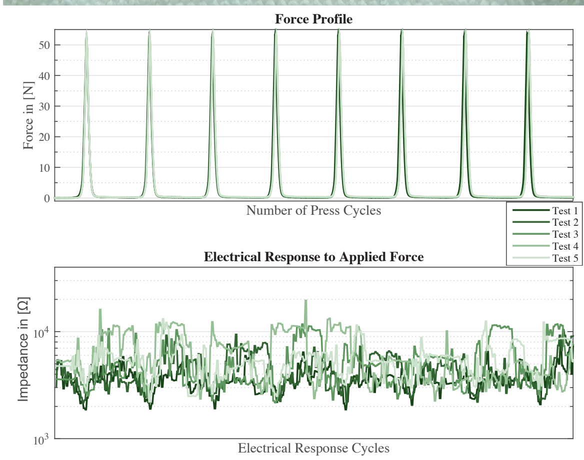
Copper Bamboo

Yarn Composition

67% Bamboo 33% Copper

No. of ends

2 ends



Company

Habu Textiles

Name of Yarn

Linen Stainless Steel

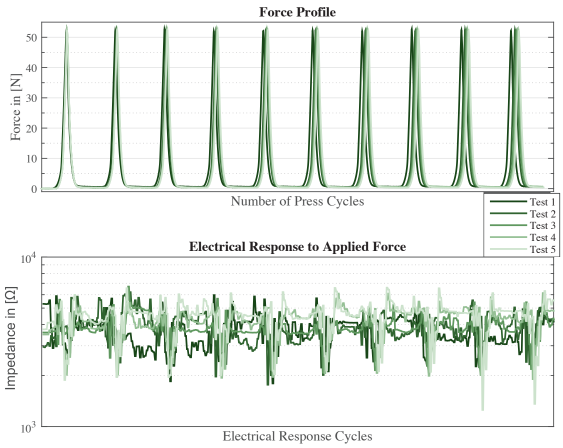
Yarn Composition

83% Linen 17% Stainless Steel

No. of ends

2 ends

Appendix E



Company

LessEMF

Name of Yarn

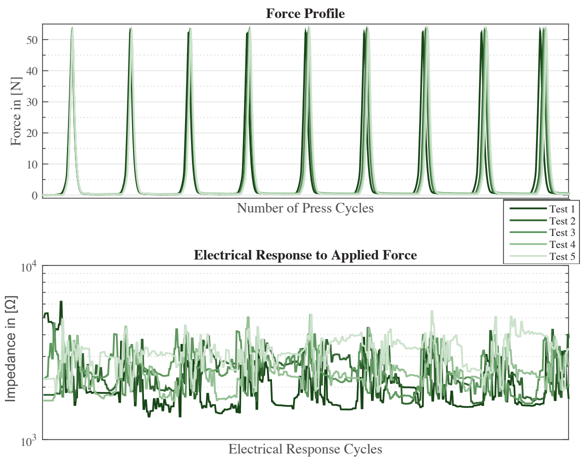
Silver Plated Nylon Conductive Thread

Yarn Composition

Silver Plated Nylon

No. of ends

1 end Silver Plated Nylon, 1 end merino wool



Company

LessEMF

Name of Yarn

Silver Plated Nylon Conductive Thread

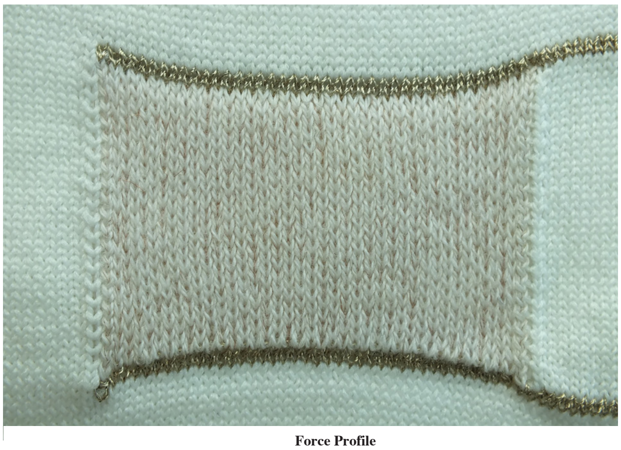
Yarn Composition

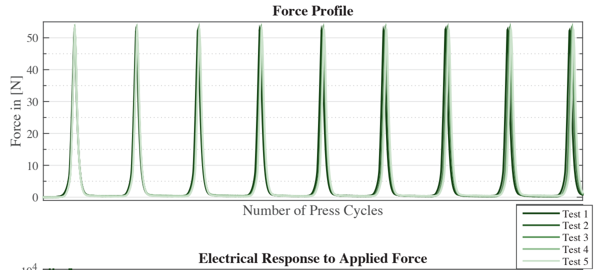
Silver Plated Nylon

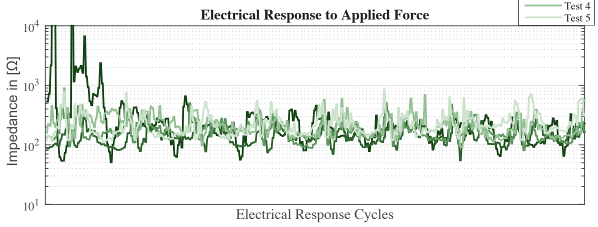
No. of ends

1 end Silver Plated Nylon, 1 end polyester

Appendix E







Company

Habu Textiles

Name of Yarn

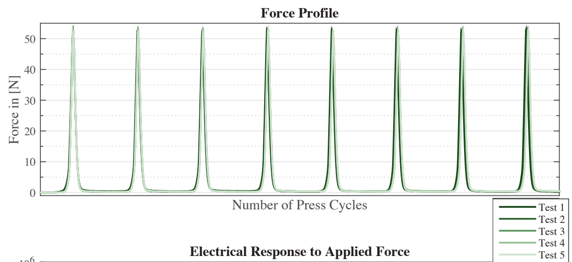
Super Fine Copper

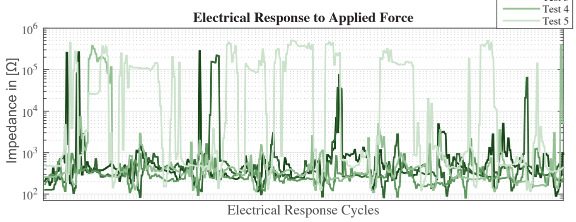
Yarn Composition

100% Copper

No. of ends

1 end copper, 1 end merino wool





Company

Habu Textiles

Name of Yarn

Super Fine Copper

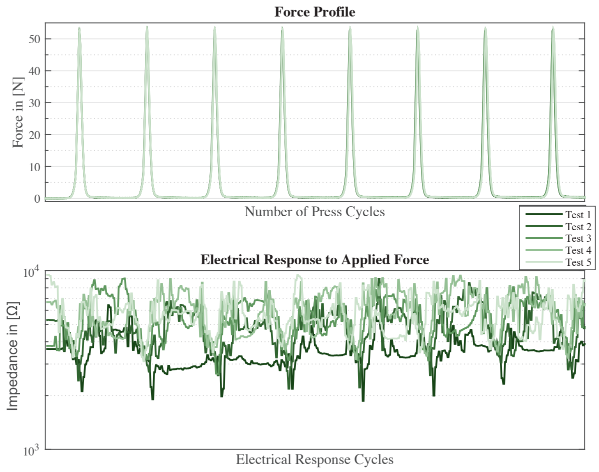
Yarn Composition

100% Copper

No. of ends

1 end copper, 1 end polyester

Appendix E



Company

Swicofil

Name of Yarn

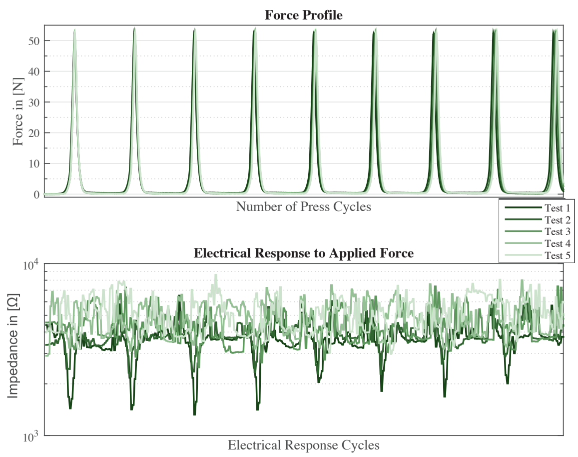
Bekaert Bekinox® VN

Yarn Composition

100% Stainless Steel

No. of ends

1 end stainless steel, 1 end polyester



Company

Swicofil

Name of Yarn

Bekaert Bekinox® VN

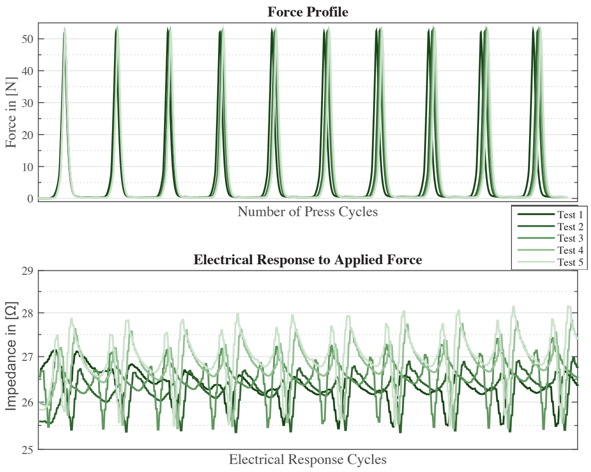
Yarn Composition

100% Stainless Steel

No. of ends

1 end stainless steel, 1 end merino wool

Appendix E



Company

Imbut

Name of Yarn

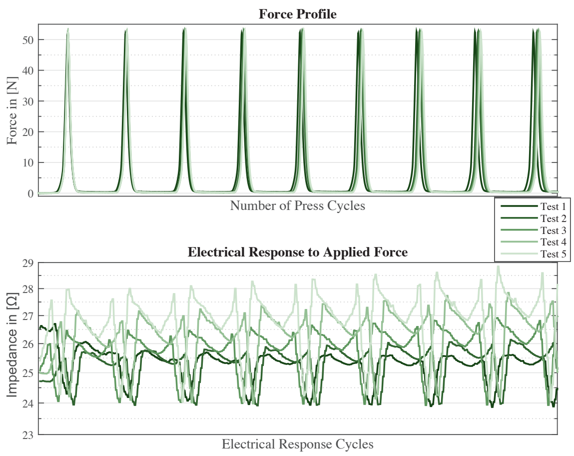
ELITEX®

Yarn Composition

>99% Silver coated Polyamid

No. of ends

1 end Silver coated Polyamid, 1 end merino wool



Company

Imbut

Name of Yarn

ELITEX®

Yarn Composition

>99% Silver coated Polyamid

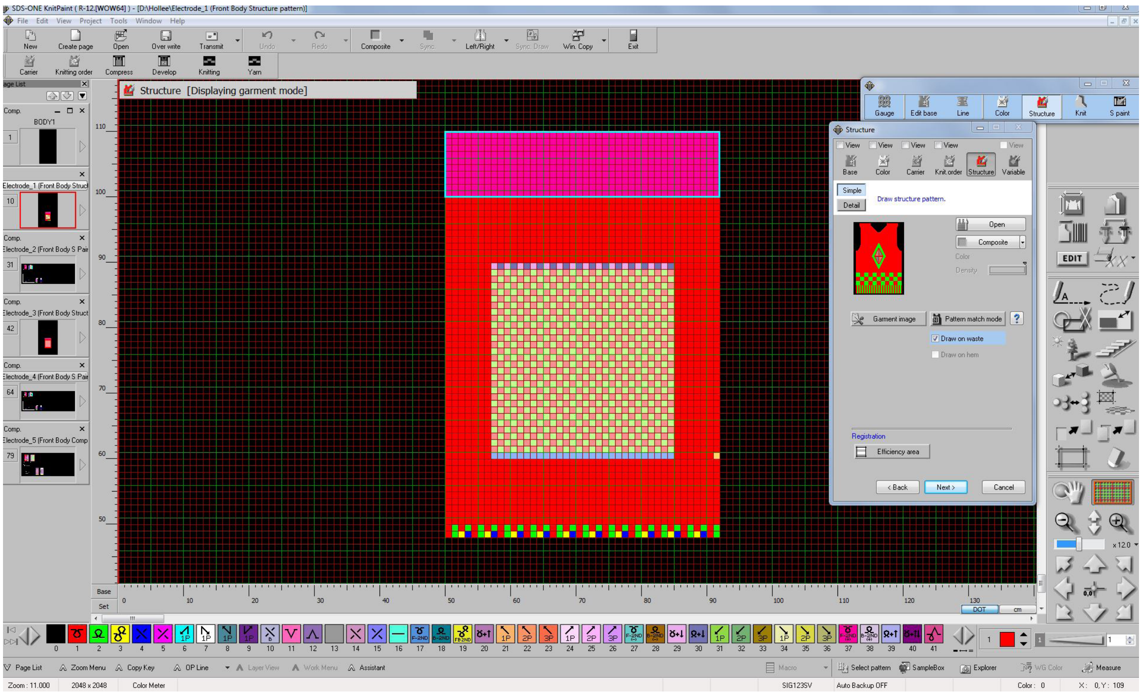
No. of ends

1 end Silver coated Polyamid, 1 end polyester

Appendix F

Development of Textile Electrodes

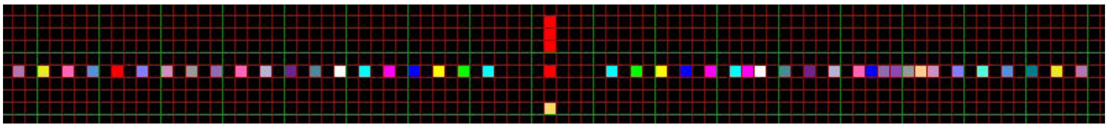
During the development of the textile electrodes the focus was on the construction of a stable structure. The first textile electrode, **Electrode_1**, was developed using an interlock technique which was square shaped.



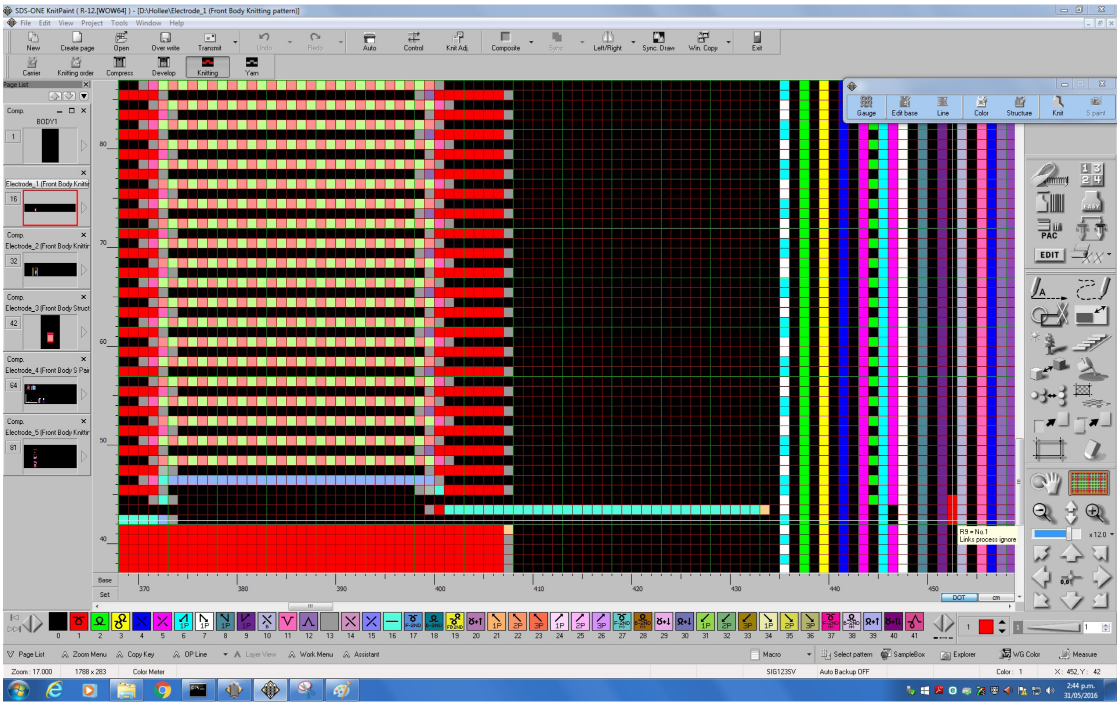
The conductive section of this sample was knitted as an interlock structure which used the stitch codes 51 and 52. As the interlock structure uses both front and back bed needles a row of alternative stitches using 29 and 30 are used on the last row of the sensor. This stitch formation informs a transfer process setting the structure up for front bed knitting, transferring any back bed stitches to the front bed.

Colour no. 79 was used to set up the interlock structure where package colour no. 103 worked in conjunction with second stitch. Second stitch allows the stitch size, in regards to stitch tightness, to be adjusted manually on the knitting machine. See package on following page.

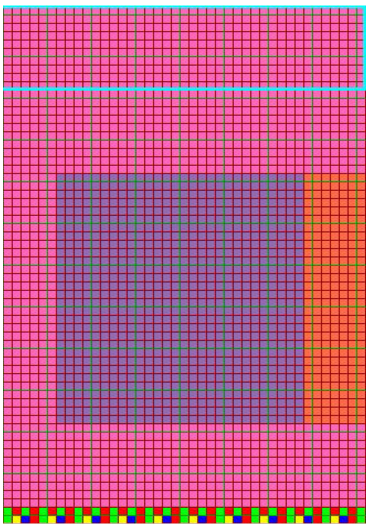
Appendix F



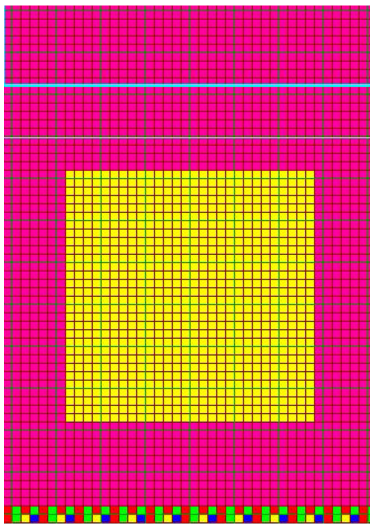
Package developed for Electrode_1



View of options lines where the package can be seen in option line R9

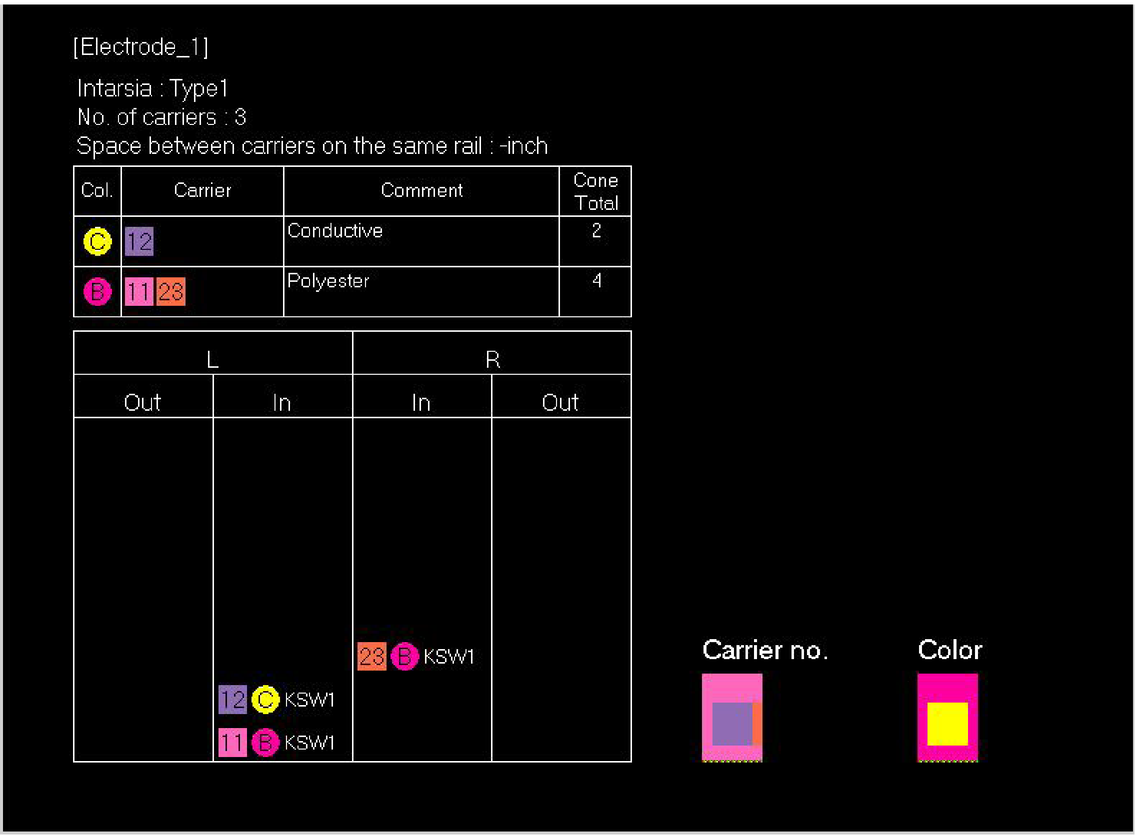


Carrier page



Colour page

Appendix F



Develop page

First textile electrode

Appendix F

Sensor Sizing

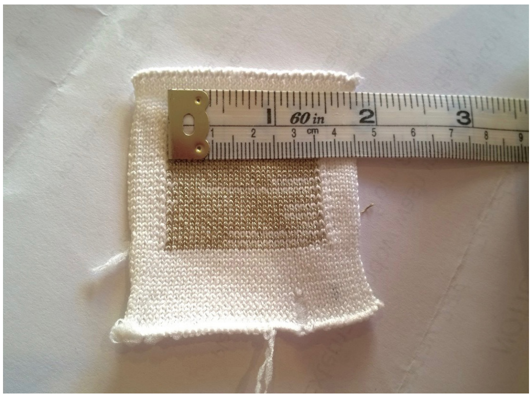
A sample size of 10x10 cm was constructed with the sensing patch size of 5x5cm. The first knitted electrode was examined and measured to determine the size adjustments needed to develop the right sized sensor. Sample sizing can be effected by stitch structures, loop sizes and the type of yarn used.

When re-sizing the knit, samples need to be steamed before measurements are taken to provide a more accurate sizing.

Sample measurements

Total Width = 5.5cm

Total Height = 6cm



Conductive sample

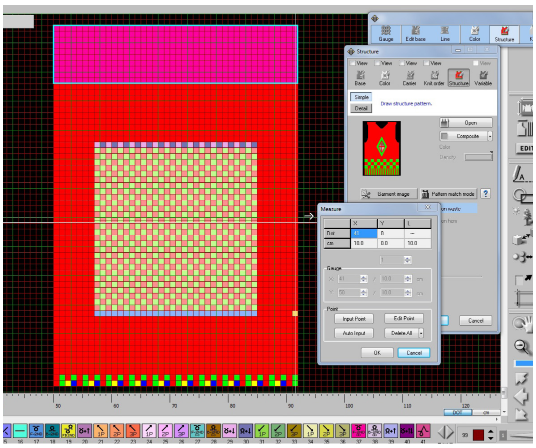
Width = 3.5cm

Height = 3cm

Changing the pattern size & working out required adjustments

Wales and courses needs to be measure in KnitPaint using the measure tool.

Wales= 28   Courses = 28



Example of measuring wales using measuring tool in Knit Paint

Appendix F

To figure out how many additional wales and courses were need within the knit structure to achieve the correct sizing, a basic equation was followed. This equation was applied to all knitted electrodes which were developed

Width

28 (wales) / 3.5 (width of conductive sample) = 8 (wales per cm) x 5 (desired measurement in cm)

= 40 wales would be needed to give the correct sizing.

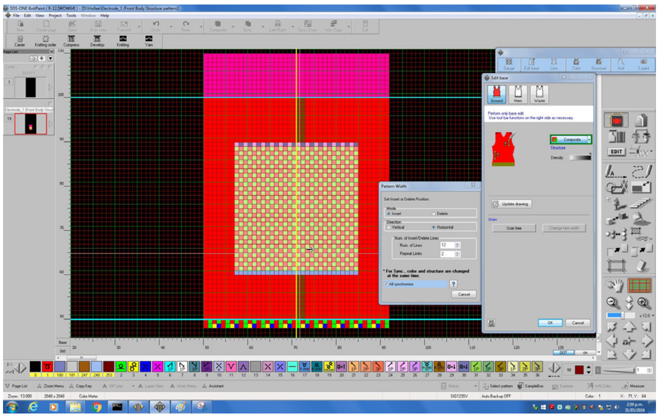
40-28=12 (12 wales need to be added in sample structure).

Length

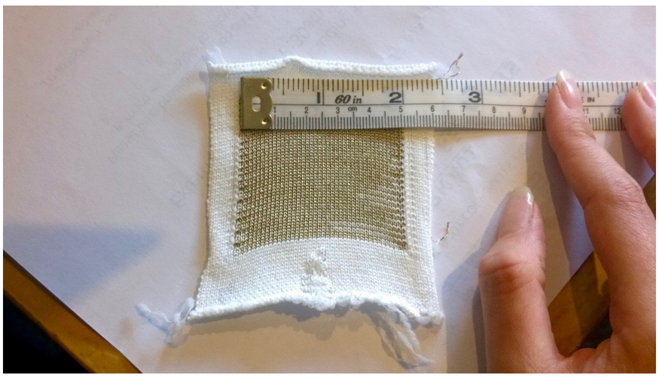
Courses/cm = 30/3 = 10. For 5cm length, 5 x 10 = 50 courses needed to give the correct sizing. 50 - 30 = 20 additional course needed

Adding these extra wales/courses into the structure was done via:

Base - Pattern Width - Insert horizontal or insert vertical.



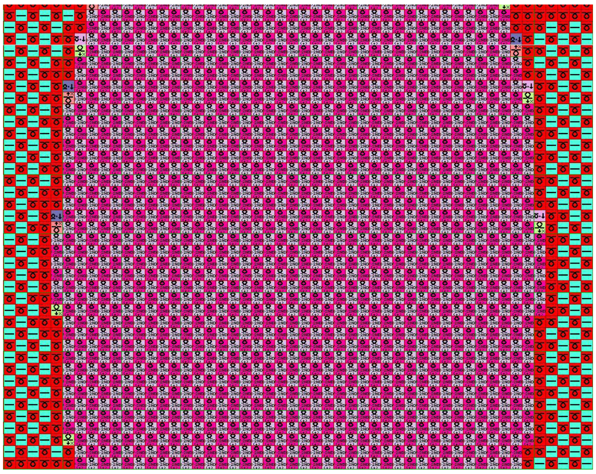
Example of courses being added into the knit structure using the Pattern Width tool



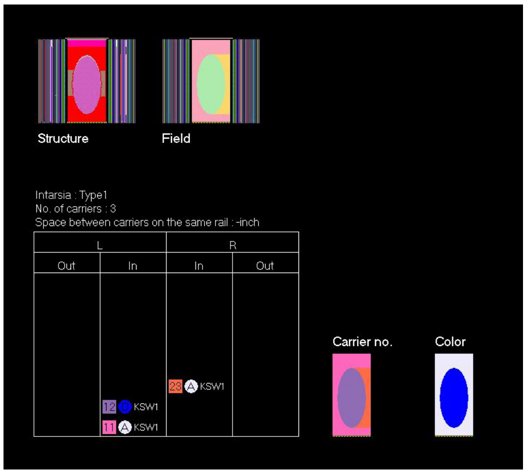
Example of electrode after being re-sized

Appendix F

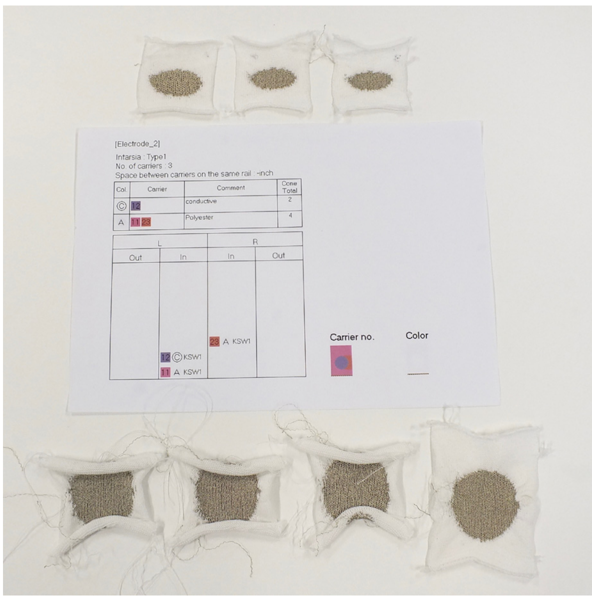
Electrode_2 - This electrode utilised the interlock technique in a circular design. Stitch codes 51 and 52 were replaced by 37 and 38. These new stitch codes worked in conjunction with colour 1 (red) in option line R9 which stopped automated front back and back front transfers. Package colour 104 was applied to the whole second stitch area. The use of the second stitch colour allow the stitch size to be adjusted only within the second stitch area (conductive section of the sample). As automated transfers were stopped, where the interlock areas began to decrease, colours 51 and 30 were used above colour 38 and colours 52 and 29 used above colour 37, this was required to start the transfer process to finish off the interlock areas. A miss knit structure was used along the main body of the interlock structure to ‘balance’ the fabric.



Structure page



Develop page Electrode_2

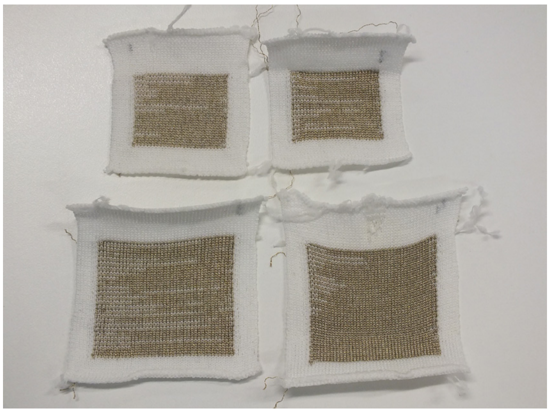


Electrode_2 development

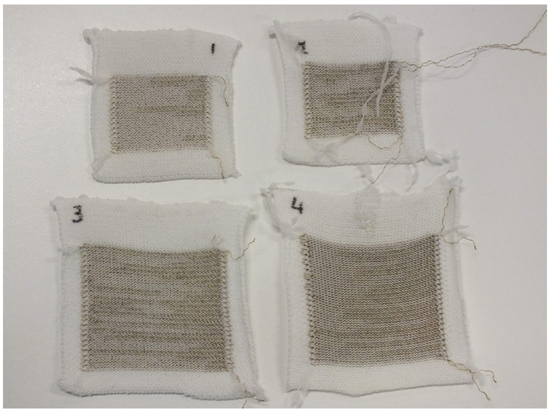
Unbalanced fabric causing bunching

Appendix F

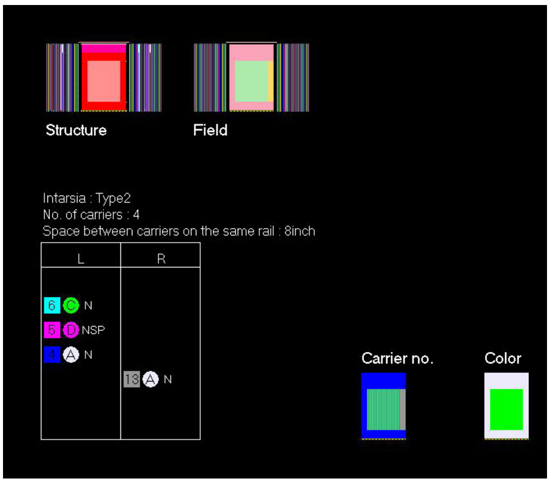
Electrode_3 - This electrode explored the technique of plating. Plating is a knit technique that feeds two yarns to each needle resulting in a different texture or colour on either side. This technique produces a stable knit suitable for the construction of a textile electrode. The conductive yarn was plated on the face of the fabric where it would be in contact with the skin. This sample was produced on the Shima Seiki Whole Garment (WG) machine which uses feeder 5 NPF (normal plating feeder). These samples underwent re-sizing and adjustments to number of yarns used while modifying machine setting. Although colour 51 was used to identify the plating there was no stitch structure change between the base fabric and conductive section.



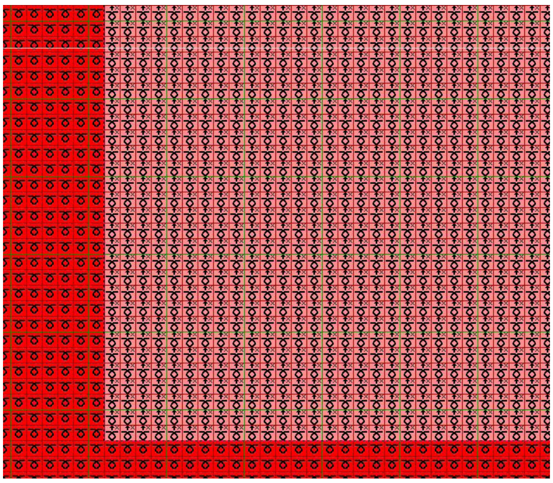
Face side of plated electrodes



Back of plated electrodes



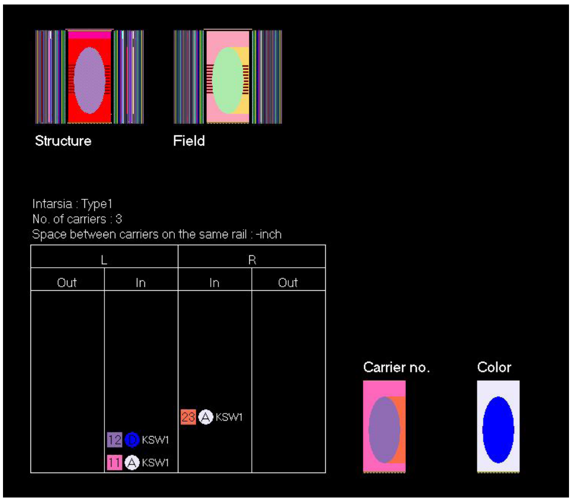
Develop page Electrode_3



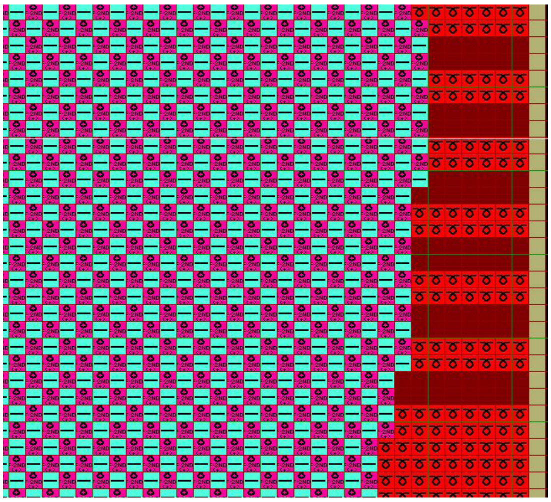
Structure page

Appendix F

Electrode_4 - Although plating provided a very stable structure it was decided that it was not an appropriate technique to use as both sides of the electrode needs to be conductive. To achieve a similar outcome a miss knit structure was developed using stitch colour 1 and 16. As previous samples had resulted in bunching around the sides, stitch colour 99 was used which holds the stitches for two courses without knitting them, resulting in a balanced fabric. Electrode_4 underwent numerous phases of development adjusting loop length by tightening the loop size and added extra ends of yarn to help stabilise the fabric. The stitch size was adjusted on the knitting machine through number 113 from the option line R13 in the package. The second stitch in this knit structure was stitch code 37 which replaced number 1. During this electrode iteration pemotex yarn was substituted for the polyester.



Develop page Electrode_4

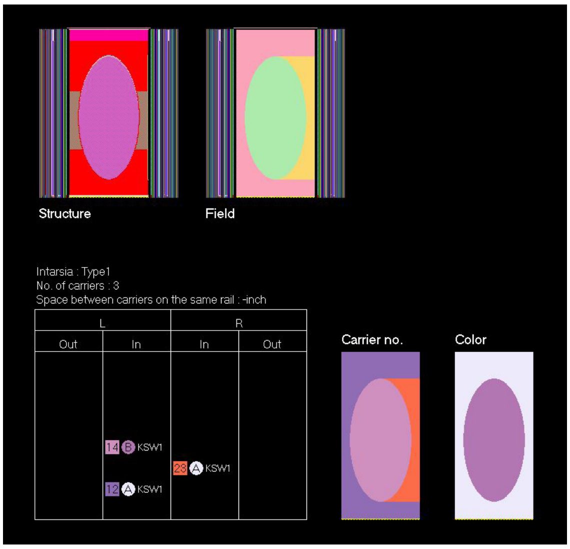


Structure page

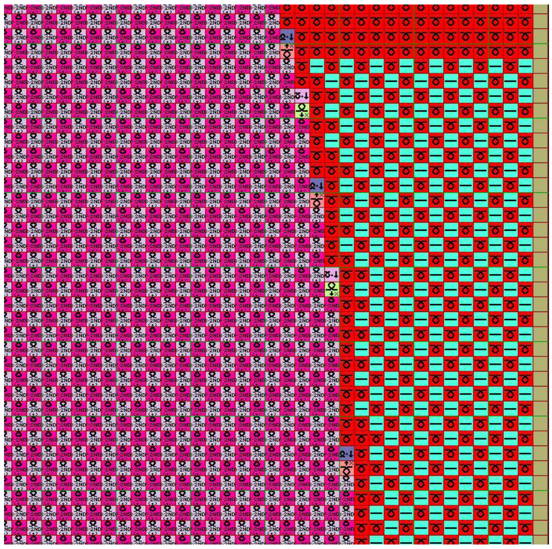
Developed electrodes

Appendix F

Electrode_5 - This textile electrode which was a further development of electrode_2, became the most successful in terms of a stable and well balanced fabric. This electrode was developed in two different sizes for ECG monitoring. These electrodes were used in the prototype phase when testing the heart rate monitor.



Develop page Electrode_5



Close up of structure page

2 sizes of Electrode_5 used for ECG monitoring

Appendix G

Textile Fibre Properties

		Natural Fibres					Man-made Fibres			
							Non-synthetic/Regenerated		Synthetic	
		Cotton	**Linen (Flax)**	**Jute**	**Wool**	**Leather**	**Bamboo**	**Tencel**	**Nylon**	**Polyester**
Fibre Characteristics	**Strength**	Strong to very strong	Very strong	Fair	Weak	Very strong	Very strong	Very strong	Strong to very strong	Strong to very strong
	Absorbency	Good moisture absorbency	Good to very good moisture absorbency	Moderate	Good to very good	Good	Very good	Very good	Low moisture absorbency	Poor
	Sunlight Sensitivity	Good resistance to sunlight	Good resistance to sunlight	Poor - rapidly looses strength	Poor	Poor	Anti-ultraviolet nature	Fairly good	Fair to good	Good
	Effect of Micro-organisms & insects	Susceptible to micro-organism	Susceptible to micro-organisms	Very susceptible to micro-organisms	Susceptible to both	-	Anti-bacterial and anti-fungal	Anti-bacterial	Resistant to all organisms	Resistant to all organisms
	Elasticity	Inelastic	Inelastic	Inelastic	Very good	Fair	Very good	Good	Very good	Good
	Warmth/thermal properties	Good conductor of heat – 'cool' fibre	Good to very good conductor of heat – 'cool' fibre	Low thermal conductivity, good insulator - 'warm' fibre	Poor conductor of heat – 'warm' fibre	Poor conductor, good insulator when dry	Thermal regulator	Thermal regulator	Poor conductor – 'warm' fibre	Insulator of heat - 'warm' fibre
	Abrasion Resistance	Fairly good	Fair to poor	-	Good	Good	-	Fairly good	Very good	Good to very good
	Breathability	Very good	Very good	Very good	Very good	Good	Very good	Very good	Poor	Poor
	Durability	Good	Good	Fair	Very durable	Good to very good	Very good	Very good	Good	Very durable

Information was gathered and compiled from the following source:

Gohl, E., & Vilensky, L. (1993). Textiles for modern living (5th ed.). Melbourne, Australia: Longman Cheshire.

Appendix H

Felted Fibre Investigation

Weighing out fibres

Making fibre batt

Laying of fibres to produce fibre batt

Appendix H

Felted wool batt

Wool fibres

Felted linen batt

Linen fibres

Appendix H

Felted tencel batt

Tencel fibres

Felted bamboo batt

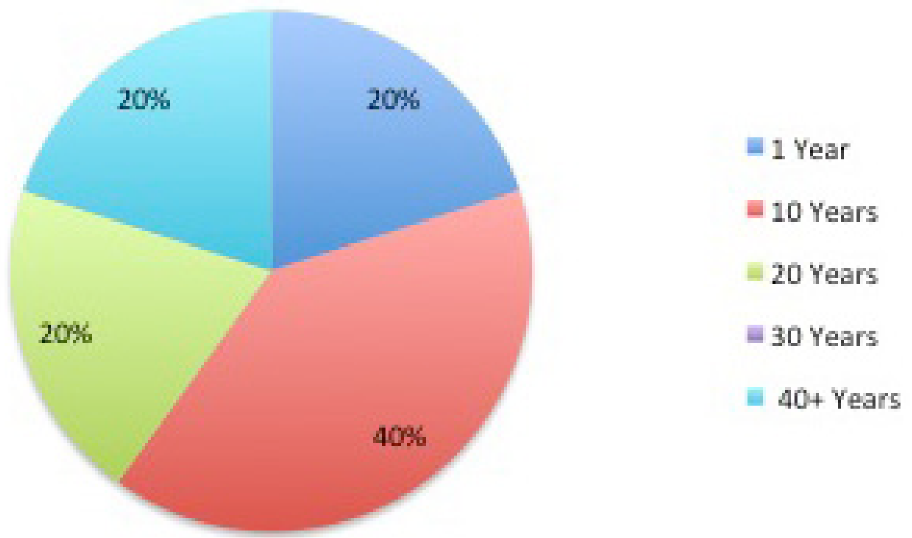
Bamboo fibres

Appendix I

Expert Inquiry - Analysis

The expert inquiry phase, consisted of an initial questionnaire which was sent to equine veterinarians. This questionnaire provided to be an indicator that smart textiles could be a beneficial aspect within the equine community focusing this research within the area of ECG monitoring.

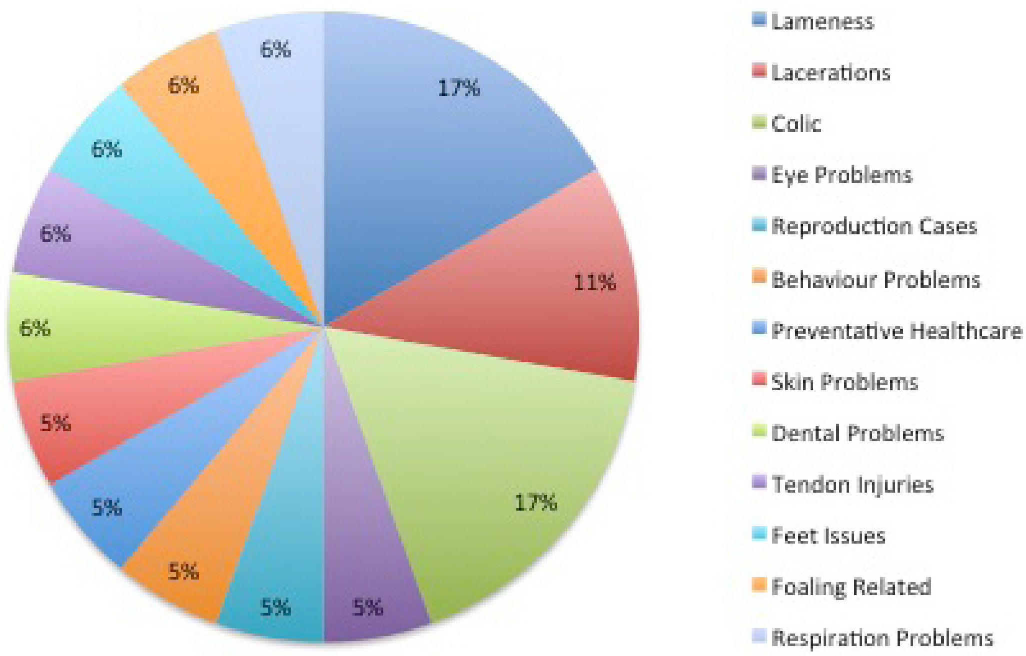
1. How many years experience do you have in the equine industry?



A range of experienced veterinarians responded to the questionnaire providing the research with a variety of experience. This knowledge acquired from both university degrees and practical experience gained throughout their careers influenced their responses. Experienced vets with 1 to 40+ years working in the equine industry, provided this research with a good indication of an area that could benefit from the use of smart textiles.

Appendix I

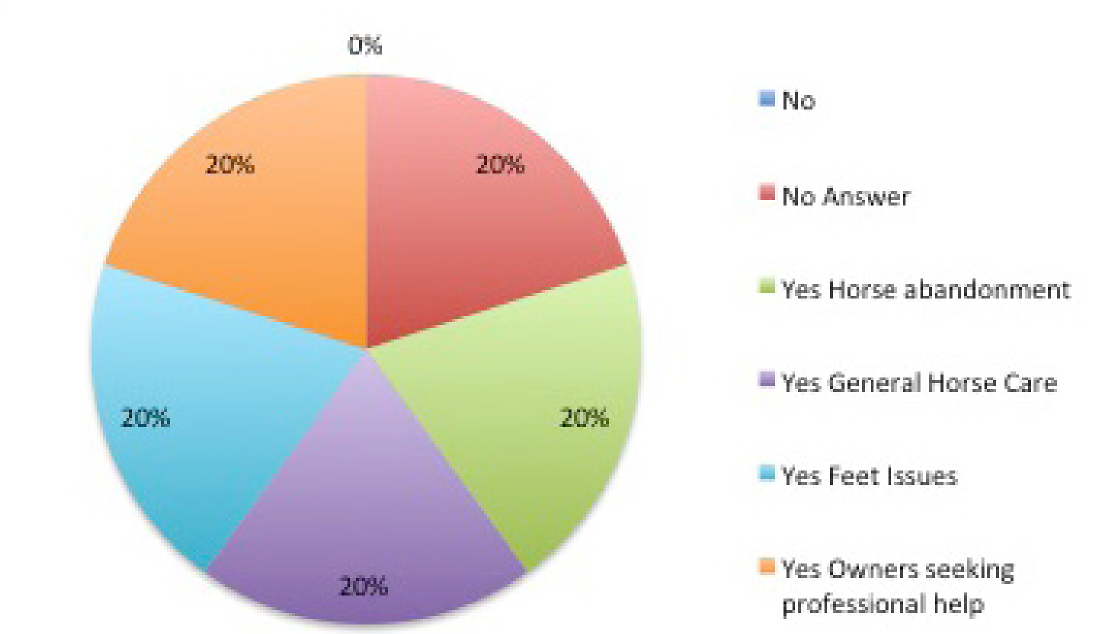
2. What are some major issues or injuries that you commonly see within equine health?



All responding participants were veterinarians, some of which specialised in equine care such as equine breeding and surgery while other worked as mixed animal vets. It was apparent that common injuries and issues varied depending on the area in which the vet specialised. A range of issues and injuries arose that varied depending on the field of expertise. Although these vets mentioned a range of injuries varying between eye, skin, dental, hoof, tendon and respiration problems to behavioural, reproduction and foaling related issues, it is clearly evident from the data collected that lameness, lacerations and colic are common problem experienced by all vets working within the equine field.

Appendix I

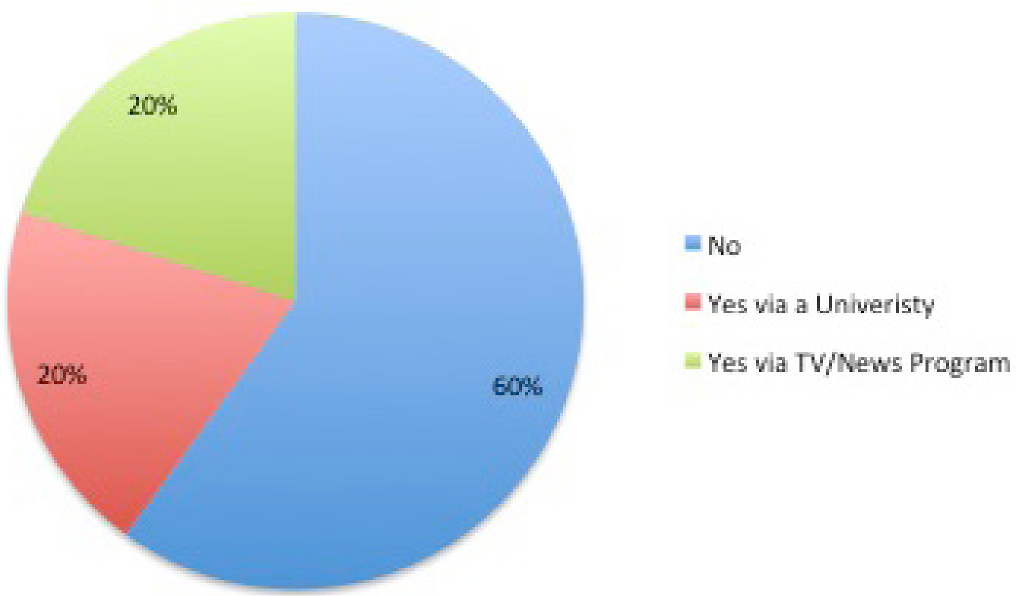
3. Is there a specific area of equine care that you think could be improved?



When asked if a specific area of equine care could be improved, 80% of the veterinarians response was yes. Areas of improvement which were mentioned were evidently linked to the responses of the previous question. Mix animals vets responses were largely based on owners knowledge of equine healthcare and raised the issue of poor awareness of equine health problems. Issues such as hoof problems and when to seek professional care, which in some cases is due to insufficient financial support and time, were discussed. However in saying this, it was mentioned that the majority of horses receive satisfactory care from their owners.

Appendix I

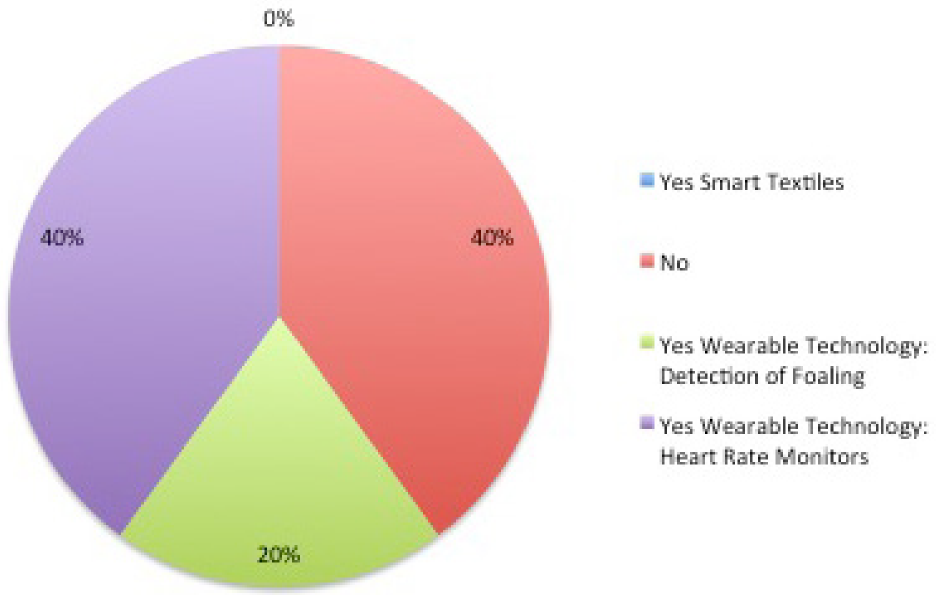
4. Prior to reading the information sheet had you heard of smart textiles before?



The majority (60%) of participants had never heard of smart textiles before prior to reading the information sheet provided with the questionnaire, which gave a brief description of smart textiles. Those that had previous knowledge of smart textiles had been exposed to this technology through either a university or a news/technology television programme. The lack of exposure to this technology provides evidence that even though smart textiles is a growing area of development within medical and healthcare, the knowledge of this technology is only slowly making it into the public sector.

Appendix I

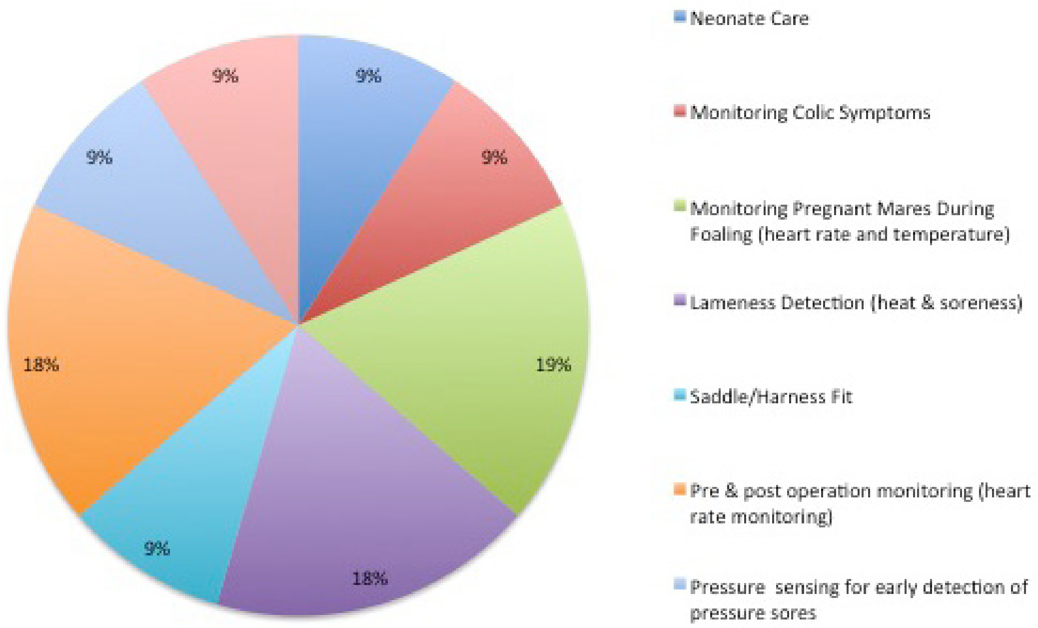
5. Are there any current uses of smart textiles or wearable technologies in equine care that you know of?



As an important question within this research, it was critical to find out what technologies are currently being used within the equine healthcare sector and if any of these involved smart textiles or wearable technology. 40% of participants were not able to identify a wearable technologies product or advise of any smart textiles being used within equine care. Although the participants were unsure whether or not these products incorporated smart textiles the other 60% knew of some form of wearable technology that is currently being used. None of the participants mentioned any exposure or personal use of these technologies. It does, however, shows that there are products making their way into the equine sector but not in the form of smart textiles. With 20% of the participants mentioning the use of wearable technology for the detection of foaling and 40% for remote ECG monitoring, none of these technologies were being employed by any of the participating vets.

Appendix I

6. After reading the information sheet, or from your current knowledge, are there specific areas where smart textiles may have a place/potential within equine care?



The objective of this question was to provide the research with a direction to pursue that would allow the focus of this project to be applied in an area, which would be of value to the veterinarian community. The responses indicated that smart textiles could have vast potential within equine care. A range of areas were mentioned most of which require some form of constant monitoring. Injuries and issues which are commonly seen were mentioned, confirming that these areas of equine health care could benefit from advantages of new technology such as smart textiles.

Appendix I

Areas such as lameness which has proven to be a common issue throughout this questionnaire is usually a tedious and multi-step process to diagnose the origin of the cause. Something so technical would require extremely advanced smart textiles. Three of the areas which were mentioned within this questions; neonate care (9%), monitoring of pregnant mares (19%) and pre and post operation monitoring (18%) all require similar monitoring aspects. The monitoring of heart rate in these cases can be vital to the survival of the animal. With the potential for smart textiles to provide constant real time monitoring this motivational my research to pursue heart rate monitoring using textile electrodes. With the potential for smart textiles to constantly monitor heart rate, this could provide three potential areas within equine care with smart textile monitoring.