Wearing Your Recovery

A human-centred study exploring how garments and e-textiles, specifically nanofiber yarns and 'bead' textile structures, can mediate stroke recovery.

Laura J Salisbury

PhD Thesis

Funded by:

THESIS DECLARATION

This thesis represents partial submission for the degree of Doctor of Philosophy at the Royal College of Art. I confirm that the work presented here is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

During the period of registered study in which this thesis was prepared the author has not been registered for any other academic award or qualification. The material included in this thesis has not been submitted wholly or in part for any academic award or qualification other than that for which it is now submitted.

Signed:

Laura J Salisbury

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ABSTRACT

"I do have a life outside of life does exist outside of

Stroke is often a sudden, life changing event from which the pursuit for 'normalcy' and or regaining one's 'self' in the context of ability, mood, and lifestyle associated behaviours can be challenging. Upper limb paresis presents a significant issue affecting approximately 87% of stroke survivors. Indeed, deficits in strength and motor control, ' are 'at the core of stroke-related disability'. Yet currently there exists no officially proven 'treatment' for upper limb impairment, nor any form of rehabilitation that has 'meaningful impact at the level of impairment'.

Only half of all stroke survivors with an initial plegic (paralysed) upper limb regain 'some useful' function after six months. Current treatments are often primitive and lack evidence supporting their clinical effectiveness, with exercise programmes being difficult to maintain and failing to accommodate lifestyle choices and behaviours of the individual. Furthermore, there exists variations in post-stroke experiences depending on the level of deficit, geographical location (for availability and access to treatments) and behavioural attitudes that impact the course of recovery.

One year post-stroke upper-limb deficits are closely linked to declining states of mental health, specifically anxiety. This, along with the need to continually persist with rehabilitation has a direct impact on recovery, diminishing quality of life as individuals are expected to become 'athletes of their condition'.

rehabilitation you know, rehabilitation."

Anon. patient quote
Clinical observation
Follow up assessment
28/01/2018

Stroke incidence is set to increase by 123% over the next two decades. Where access to healthcare lags the improvement in nutrition in developing low-middle income countries and the costs of traditional stroke therapy are outside of the means of many individuals, mobile-based methods may be very important for these large populations. Further, current methods are not best suited for current and emerging lifestyles. This thesis addresses these two main areas through the lens of the garment. In doing so, the aim of this research is to therefore evaluate the potential for garments and e-textile to mediate stroke recovery.

By drawing upon the regular, 'intimate' correspondence the garment holds with the body, this PhD research re-considers the delivery and positioning of rehabilitation interventions relative to highly complex associations with 'being' and 'becoming'; including identity and behavioural traits post-stroke. Rather than targeting time in therapy, this research presents a line of inquiry to enhance recovery at times between therapy, enhancing mobility, personal independence, and agency during activities of daily living across 'public' and 'private' contexts.

With approximately 1.2 million incidences of 'first time strokes' per year worldwide and this number set to rise by 123% over the next 20 years, delivering appropriate and effective treatments that are intuitive, easy to use and complimentary to spontaneous use in lifestyles is a top priority.

The PhD identifies that textile-based technologies have a compelling advantage in the frequency and manner in which the wearer engages with them that can influence the course of post-stroke recovery. Beyond this the research aims to understand the key elements of a garment that are expected, 'familiar', and desired, in order to utilise these qualities to improve uptake, compliance and integration of the intervention within contexts of everyday living.

The capability of garments to influence mood, behaviour and personal identity is widely known and appreciated within the literature. Where, the use of a garment as a medical device or intervention is not new, the manner in which it is used and its position within care lacks critical review. In view of this, this thesis evaluates the use of garments as therapeutic interventions and identifies key opportunities and challenges for doing so. Findings from technical experiments, design practice and people-centred studies carried out in this thesis support this proposition, further advancing the body of knowledge in this area. A discussion of the garment as an intervention and findings from the experiments are included in three rapid, iterative, user experience case studies (Chapter four) and one major case study (Chapters five to nine).

Notably, the major case study takes a practice-based approach in investigating the key underlying mechanisms that contribute to upper limb functional recovery, with a focus on how the components embedded in the garment itself could help modify levels of reticulospinal and corticospinal input to improve functional recovery of the upper limb. Methods of using nanofiber yarns and a novel 'bead' component are developed within this research to target forearm flexors and extensors, forming the major case study exploring the use of garments as an interventional tool.

In summary, this thesis introduces a methodological framework that may be implemented within other wearable healthcare research and development projects, as well as a critique of the positioning of the garment as a therapeutic device to inform future material development directions. In doing so, this thesis has begun to pave the way for intersecting materials science, design and neurology in developing new textile components with promising opportunities for future research in personalised and accessible healthcare.

TABLE OF CONTENTS

LIST OF TABLES & FIGURES

CHAPTER 4.0

CHAPTER 5.0

CHAPTER 6.0

CHAPTER 7.0

CONCLUSION

APPENDICES

APPENDIX 2.1

APPENDIX 2.1

APPENDIX 2.3

APPENDIX 2.4

APPENDIX 2.5

APPENDIX 2.6

APPENDIX 2.7

VIDEO PLAYLIST

Where QR codes have been included in the figures to provide access for the supportive videos, a playlist has also been created on vimeo as an alternative. The complete links are included below as reference. Please use password THESIS2021 to gain access.

Methodology:

Figure. 0.2.9 'Under Development': Visualising the body post stroke via body scanning. A visual of early scan data
Body scan 1 link: ***https://vimeo.com/517769226***
Body scan 2 link: ***https://vimeo.com/517769249***

Chapter 4.0: Embedding rehabilitation into a garment

Figure. 4.15 Sleeve toile connected to power supply prior to testing
Link: ***https://vimeo.com/517769970***
Figure. 4.17 Dress demo: Changing sleeve shape to generate limb awareness
Link: ***https://vimeo.com/517769935***
Figure 4.24 Pemotex ribbon, conductive yarn and Lycra: Using electrical energy to induce shape changes and counteract gravitational forces
Link: ***https://vimeo.com/517770469***
Figure 4.25 Demonstrating thermal conduction via heat gun
Link: ***https://vimeo.com/517770109***

Chapter 7.0: Manipulating textile softness

Figure. 7.15 Participant discussing sleeve length in response to Sample 31
Link: ***https://vimeo.com/517772437***
Figure 7.17 Participant response to Sample 32
Link: ***https://vimeo.com/517770179***
Figure 7.18 Close-up of surface structure with protruding PVDF stitches
Link: ***https://vimeo.com/517770400***

Chapter 8.0: Yarn design, construction, experimentation and testing

Figure. 8.20 Oscilloscope observations of Specimen Si16
Link: ***https://vimeo.com/517772237***
Figure 8.26 Nanofiber separation from the core yarn
Link: ***https://vimeo.com/517772366***

Chapter 9.0: Exploring garment specifications

Figure. 9.24 Full bead render - Link: ***https://vimeo.com/517769903***
Figure 9.26 Half bead render - Link: ***https://vimeo.com/517770061***
Figure 9.31 Final prototype: Inside of the garment
Link: ***https://vimeo.com/517770007***
Figure 9.36 Final prototype - Link: ***https://vimeo.com/517770035***

Appendix 2.2: A practice diary: Supplementary sample photos

Figure A2.27 Lino weave. The development of movement: Part 1 - Gather
Link: ***https://vimeo.com/517772523***
Figure A2.28 Lino weave. The development of movement: Part 2 - Pleat
Link: ***https://vimeo.com/517770271***

Appendix 2.6: Sample specification (Sample Series I)

Table A2.61: Sample specification (Digitally knit samples from Sample Series I)
Link: ***https://vimeo.com/517770336***

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In loving memory of my Nan, Grandpa and Grandad

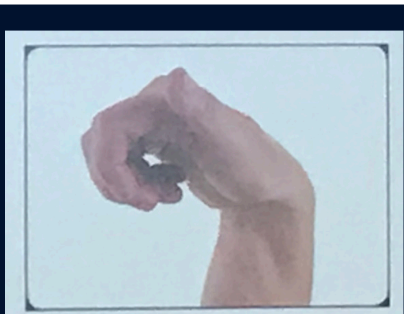
INTRODUCTION

0.1.1 Contextualising the research

Upper limb paresis is a debilitating consequence of stroke and other neurological disorders, affecting approximately 87% of stroke survivors (Parker et al., 1986) and approximately 25% of surviving term infants (Inder and Volpe, 2018). Only half of all stroke survivors with an initial plegic (paralysed) upper limb regain 'some useful' function after six months (Kwakkel, 2003), with issues persisting after four years in around 50% of individuals (Broeks, 1999).

Activities of daily living (ADLs), such as feeding oneself, dressing, washing and basic hygiene are largely dependent on arm function (Sveen, 1999). Engaging with ADLs can be difficult following upper limb paresis, impacting quality of life.

As a result of upper limb paresis the flexor muscles become increasingly active, in some cases, developing into spasticity (Zaaimi et al., 2012). In contrast, varying levels of weakness are experienced in the extensor muscles. This depression of strength, control and reflexes can lead to hyperreflexia, overactive or over responsive reflexes, and increased tone resulting in clear changes in limb posture and positioning (Figure 0.1). Consequently, a loss of finger extension can occur, negatively impacting the ability to grasp (Zaaimi et al., 2012) and perform finer motor control.



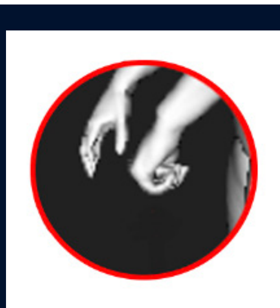


Figure. 0.1.1 Left: Visualisation of changes in limb posture and positioning (Zaaimi et al., 2012); Right: Participant body scan (Author's archive)

Deficits in strength and motor control, defined as 'the ability to make coordinated, accurate, goal-directed movements (Krakauer, 2005), are 'at the core of stroke-related disability' (Krakauer and Cortes, 2018). The prevalence of weakness demonstrably has a profound impact on the physical identity of the individual. This can cause stigma and is hence disguised or hidden; leading to self-isolation and avoiding public spaces from time-to-time: "I just want someone to look at me, not always at my arm" (AA, 2018).

One year post-stroke, upper limb deficits are closely linked to declining states of mental health, specifically anxiety (Morris, 2013). Within the Cochrane systematic review of upper limb rehabilitation (Pollock et al., 2014a), long-term upper limb deficits were reported to have an association with ‘poorer perception of health-related quality of life’ (Franceschini, 2010) and subjective well-being (Wyller, 1997). Indeed, management strategies for anxiety are considered to improve health related quality of life and participation in rehabilitation activities (Morris, 2013).

The restoration of extensor muscle use by improving strength is a common, important aim within rehabilitation (Zaaimi et al. 2012). Improving upper limb function in general is a core element needed to reduce disability and maximise patient outcomes (Pollock et al., 2014a). Currently there exists no officially proven ‘treatment’ for upper limb impairment (Stockley, 2020), nor any form of rehabilitation that has ‘meaningful impact at the level of impairment’ (Krakauer and Cortes, 2018). It is not fully understood to what extent rehabilitation techniques contribute to recovery and how much of this is a result of spontaneous biological recovery (Charlton et al., 2003). Understanding of the core underlying mechanisms that are seen to contribute towards hand function and its restoration have been explored for decades (Muir and Lemon, 1983; Lawrence and Kuypers, 1968). However, along the way, research of motor learning, inter-hemispheric imbalance, and changes in cortical excitability, functional connectivity and reorganisation have shown little to no impact on recovery (Krakauer and Carmichael, 2017; Krakauer, 2018). More work is required to better understand the impact of the underlying mechanisms on upper limb and hand function, which Chapter five explores in more detail.

However, with existing methods of rehabilitation failing to achieve the minimum guidelines of rehabilitative training required by around 240% (Wade, 2018) and input from a therapist considered rare beyond six months post stroke in the UK (Rodgers et al., 2015), there exists a real need to explore effective approaches that compliment current methods and boost gains to improve the outlook of stroke survivors. Beyond the UK, particularly within low-middle income countries (LMIC), large sections of the population lack access to health-care and guidance on health-related nutrition, rendering them to high risk of developing type two diabetes and obesity; both well-established risk factors for stroke. Moreover, the costs of traditional stroke therapy are outside their means. *“The impact of mobile-based methods, such as wearable healthcare, may be very important for these large populations”* (Baker, 2020).

With approximately 1.2 million incidences of ‘first time strokes’ per year worldwide and this number set to rise by 123% over the next 20 years (Royal College of Physicians, 2016), delivering appropriate and effective treatments that are intuitive, easy to use and complimentary to spontaneous use within existing lifestyles is a top priority.

This presents an need and opportunity for re-thinking approaches to rehabiliation to support the increase in rehabilitation requirements. This requires an understanding of the behaviour and lifestyles of survivors post-stroke that lacks documentation in the literature (Drummond, 2020).

0.1.2 Positioning the garment

The capability of garments to influence mood, behaviour and personal identity is widely known and appreciated (Simmel [1900], 1989; Goffman, 1959; Wilson, 1985; Bourdieu, 1984; Bovone and Mora, 1997; Entwistle, 2000; Ruggerone, 2017; Finkelstein, 2007; Sampson, 2018). Therefore, the use of the garment as a research tool to unpack factors related to behaviour and lifestyle is attractive.

The focus of this research is in exploring the current stroke landscape (research questions one, two and five listed below), current clothing needs to identify the current relationship between the garment and stroke survivor (research questions three and four) and thereafter the potential for using garments as next-generation therapeutic tools for influencing the rehabilitation and recovery of upper limb impairments (research questions six and seven). This will be explored throughout the thesis via three small and one large case study that aim to demonstrate how garments can provide an alternative manner, or platform for delivering treatment alongside everyday life.

Research question (i): What are the most significant challenges existing in current and near future post-stroke upper limb recovery?
Research question (ii): Why is there a need to intervene?
Research question (iii): What are the opportunities for using a textile/ garment-based intervention?
Research question (iv): What are the barriers for utilising a garment in the space of healthcare, specifically stroke rehabiliation?
Research question (v): What mechanisms contribute to upper limb function?
Research question (vi): How might a textile (component) manipulate the underlying neural pathways which dominate control of the hand and upper limb?
Research question (vii): How is the role of the wearer/ recipient of care positioned in accordance with the delivery of care and how do the material choices impact this?

The capability for garments to influence neurological responses, motor recovery and therefore, enhancing human ability is less known. The use of garments in medicine is not new (Moseley et al., 2007; Attard and Rithalia, 2010; Coghlan et al., 2019; Richards et al., 2020; Zhao et al., 2020); However, the manner in which they are used and their position within care lacks critical review. The emergence of 'wearable technology' and 'smart textiles' provides an opportunity to reconsider the positioning and provision of healthcare; blurring the boundaries between the delivery of care and everyday life, specifically in 'mobilising' healthcare by replacing *"plugged-in"* machinery as *"part of the digital health revolution"* (Joyce, 2019). Where access to healthcare and traditional stroke therapy often relies on attending clinics or having the motivation and training to pursue self-guided therapy, mobile-based methods may be very important for large populations of stroke survivors experiencing upper limb deficits beyond discharge from hospital.

The contribution of this PhD is in demonstrating how garments can mediate the experience of stroke rehabilitation, exploring key opportunities and highlighting key challenges in doing so and providing a framework that draws together disciplines of stroke, material science, electrical enginnering, fashion and textiles with inclusive design in a manner that has not been achieved before.

Key areas of exploration include: material choice, methods of integrating key materials/ components into the garment in manners that are deemed compatible with textile qualities and the type of intervention in line with medical and social needs.

The above are important because there exists a negotiation between needs of the garment, the needs of the 'medical device' functionality and the needs of the wearer. User experience becomes central to guiding developments in areas related to comfort (Chapter seven), identity (Chapters two and three) and application to lifestyles, to name but a few. Such elements can be highly subjective and are based on experiental factors. This is supplemented by, and informs a range of technical calculations and experiments exploring the early feasiblity of realising the final concept presented in case study four (Chapters five to nine).

Design research is increasingly contributing towards improving life via research into care (Rodgers, 2018), healthcare and quality of life via new experiences with wearable devices (Cutecircuit, 2019). The impact of working practically in this space is considered to contribute towards a furthering understanding of the complexities that influence recovery and life post-stroke, from an alternative perspective to the medical model[1]. By working with a people-centred, design-led approach[2], rehabilitation needs and methods are considered and questioned. Rather than replicating what has gone before, the form of rehabilitation, including the origin of care is critically examined.

[1] The medical model of disability views disability "as an impairment that needs to be treated, cured, fixed or at least rehabilitated [...] a deviation from [the norm]" (Degener, 2016). It states, therefore, that exclusion results from the impairment.
In contrast, the social model of disability views disability "as a social construct through discrimination and oppression" (ibid).
[2] 'People-centred design' or 'human-centred design' is an approach that focuses on the individuals "'users', their needs and requirements [to enhance the effectiveness], efficiency, improve [...] well-being, 'user' satisfaction, accessibility and sustainability" (International Organization of Standardization, 2019).

0.1.3 Thesis Structure and Formulation of the Research Questions

The thesis begins by introducing the theoretical framework within Chapter 0.2. ***Chapter one*** then positions the reader directly within the 'stroke landscape', providing a range of key diagrams that culminate details of the 'care system' from findings both within the literature and from anthropological study.

Chapter two proceeds with justifying the position of the research by questioning the need to intervene. It places an emphasis on not just identifying a clinical need and running with it, but taking the time to consider the wider consequences of intervening in relation to how society responds to disability and, in particular modes of care for stroke.

Chapter three positions the garment as the area of expertise that the researcher brings to the line of enquiry. It begins by focusing on the positioning garments as a research tool for investigating activities of daily living and lifestyles post-stroke in line with challenges drawn from Chapter two. Within the latter half, the chapter re-positions the garment as having notable opportunities for intervening as a 'platform for care' (pp. 107). It concludes by explicitly identifying the challenges and opportunities for using a garment as a therapeutic tool, drawing from findings within the Chapter but also from prior chapters

Chapter four builds on insights from Chapter three, to explore the positioning of the garment as a therapeutic intervention through the emergence of three case studies. The case studies explore the correspondence between transitions, boundaries and constructed hierarchies within stroke rehabilitation, examining the technical feasibility briefly, but emphasising the impact of choice of intervention on the wearer and compliance, or even willingness, to use. The iterative nature is emphasised in the chapter introduction (pp. 137) and the findings from each case study are summarised in the concluding section of the chapter (pp.160 - 161), The chapter concludes with suggestions for stepping back and investigating the underlying mechanisms that contribute to upper limb recovery in order to be better informed about suitably intervening.

Chapter five marks the start of the final and largest case study (four). The purpose of the chapter is to unpack the type of intervention and the benefits to health and upper limb recovery in more detail. It sets up expectations for reading about a stimulation protocol hypothesis, choice of materials to meet these parameters and theoretical calculations to support this.

Chapter six then proceeds to focus on one of these technologies, unpacking theories of piezoelectricity. It demonstrates the range of challenges for using said materials, requiring further investigations beyond the chapter.

Chapter seven develops a range of focus groups to explore the qualities[3] of a textile that contribute to wearability, specifically, textiles using piezoelectric materials.

[3] Specifically how to manipulate softness levels; A particular gap in the literature.

The chapter places emphasis on the importance of comfort on a wearer's compliance of wearing a garment (pp. 211) to clarify the need to investigate when working with e-textile and other components that intend on being integrated into the garment. The chapter addresses this through practical investigations, concluding with key findings that are both specific to the line of enquiry in the case study (knitting with PVDF yarns) but also with identifying techniques with handling yarn combinations, orientation and integration of components (Figure 7.25) in a manner that can be utilised beyond the case study.

Chapter eight then proceeds to conduct a range of experiments to unpack the performance of energy harvesting methods and the design of energy harvesting yarns to better understand the potential use of these materials within the intervention (pp. 255). The introduction of material characterisation techniques is particularly important here, demonstrating a further strand of enquiry that informs the researcher about the material and suitability to the intervention. The chapter concludes (pp. 292 - 293) by evaluating the performance of the yarn specimens and thoughts for improvement, but also the challenges for using this method in the intervention.

Finally, ***Chapter nine*** brings together areas investigated throughout the thesis to introduce an early garment specification. It also introduces (pp. 297) further key considerations for developing the 'device' including understanding how the wearer can control the device, identifying key risks and hazards associated with use and mis-use, as well as garment style, fit and positioning of components.

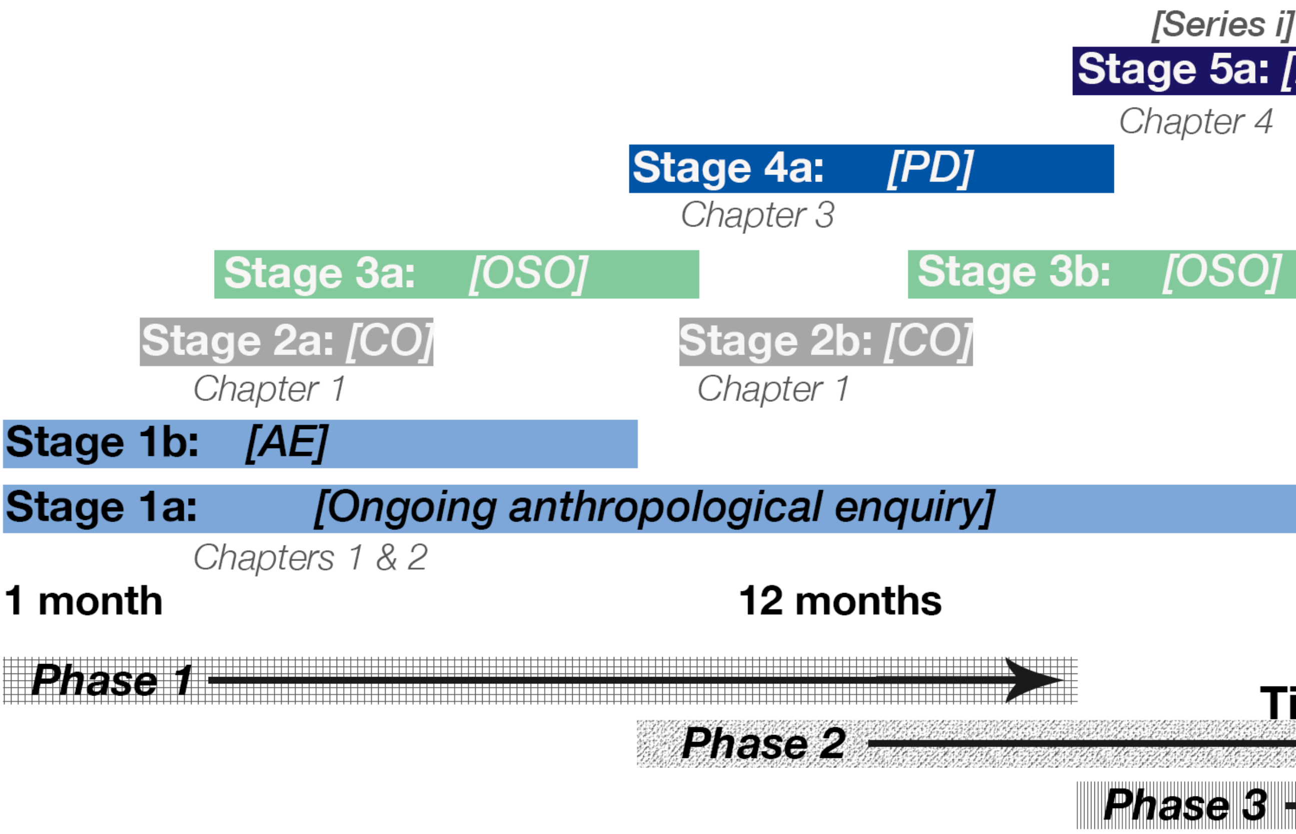
The research questions[4] and objectives are displayed in Table 0.1.2 in reference to the chapters, demonstrating the structure of the thesis whilst Figure 0.1.3 positions these relative to corresponding methods that are introduced in the next chapter; the 'Methodology'.

[4] Findings from research questions one and two were used to construct research questions three to eight.

Table 0.1.2: Research Questions and Objectives

	Phase 1: Exploring context, needs and desires	Phase 2: Investigating garments as medical interventions	Phase 3: Developing the hypothesis
Research Questions	(i) What are the most significant challenges existing in current and the near future post stroke upper limb recovery? *[Chapter one]* (ii) Why is there a need to intervene? *[Chapter two]* (v) What mechanisms contribute to upper limb function? *[Chapter five]*	iii) What are the opportunities for using a textile/ garment-based intervention? *[Chapters three and four]* iv) What are the barriers for utilising a garment in the space of healthcare, specifically stroke rehabilitation? *[Chapters three and four]*	vi) How might a textile (component) manipulate the underlying neural pathways which dominate control of the hand and upper limb? *[Chapters five, six, eight and nine]* vii) How is the role of the wearer/ recipient of care positioned in accordance with the delivery of care and how do the material choices impact this? *[Chapters five, seven and nine]*
Objective(s)	O 1.1- Establish anthropological enquiry of post-discharge community experiences and life post stroke[5]. O 1.2- Conduct a range of clinical observations of current specialist approaches to upper limb rehabilitation. O 1.3- Consult with key clinical experts in the field of stroke rehabilitation (Key advisors: Dr Rachel Stockley and Professor Stuart Baker placed throughout thesis). O 1.4- Develop a participatory design group to provide further insights of post stroke life; building on [0 1.1].	O 2.1- Use the garment as a tool to explore the relationship between the wearer and their post-stroke identity. O 2.2- Detail the range of garment values that contribute to the desire to wear along with key enquiries into this through sampling. O 2.3- Utilise the findings from [O 2.2] to comparatively analyse how the introduction of the intervention may affect desire to wear.	O 3.1- Develop prototypes and iterations of components in response to findings. O 3.2- Explore garment types and applicability to post-stroke lifestyles through participatory design methods. O 3.3- Test and characterise a range of yarns and bead structures, observing impact on output performance, textile structure and garment specification as a result.

[5] There are a lack of studies documenting long-term life post-stroke in the literature and therefore there is a need to gather primary evidence (Stockley, 2019).



Key
Stage 1: Ongoing anthropological enquiry;
Stage 2: Clinical observations ***[CO]****;*
Stage 3: *Outpatient service observations* ***[OSO]****;*
Stage 4: Participatory design group workshops ***[PD]****;*
Stage 5: Responsive sampling ***[RS]***;
Stage 6: Focus group ***[FG]***;
Stage 7: Material characterisation and performance tests ***[MC/T].***

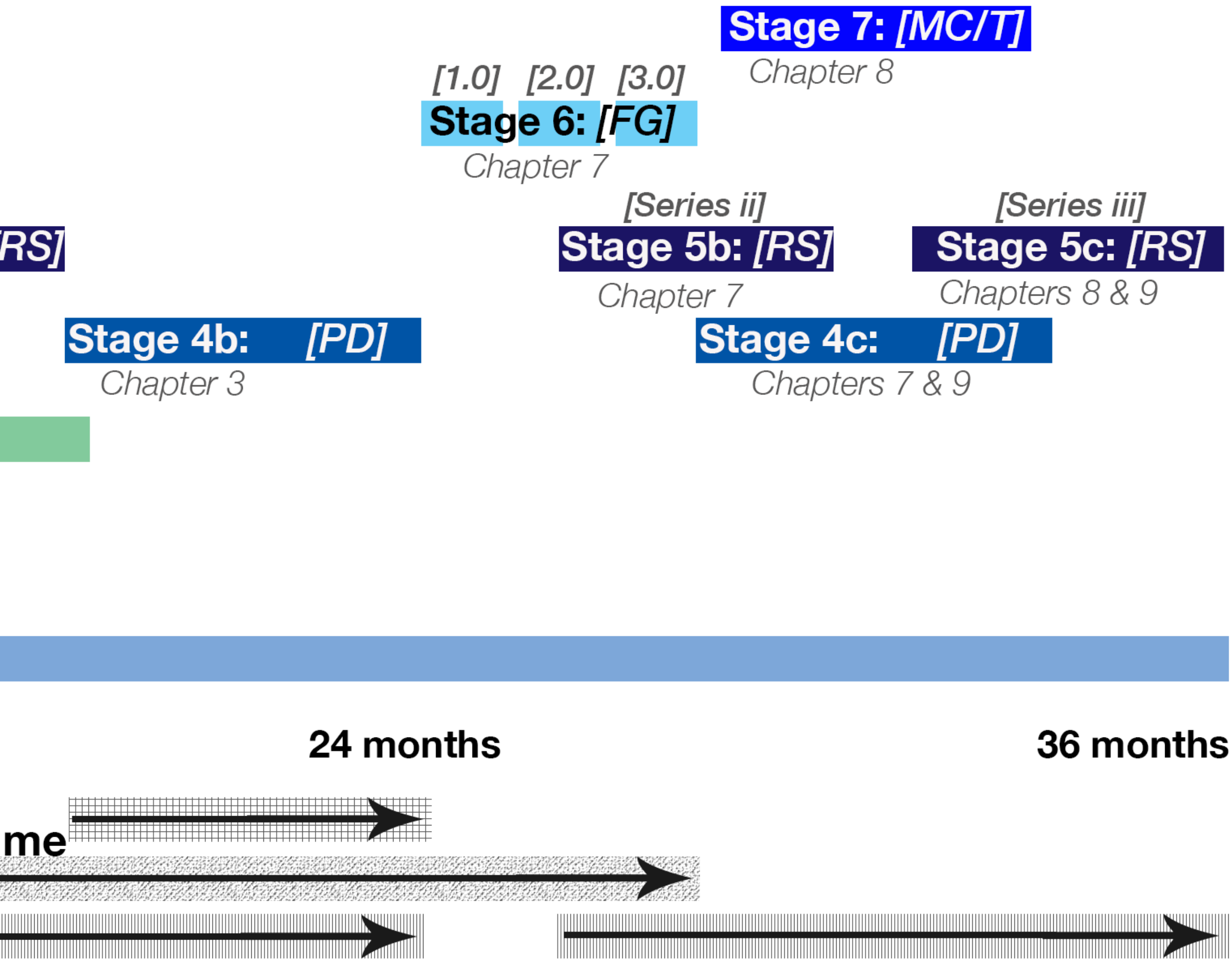
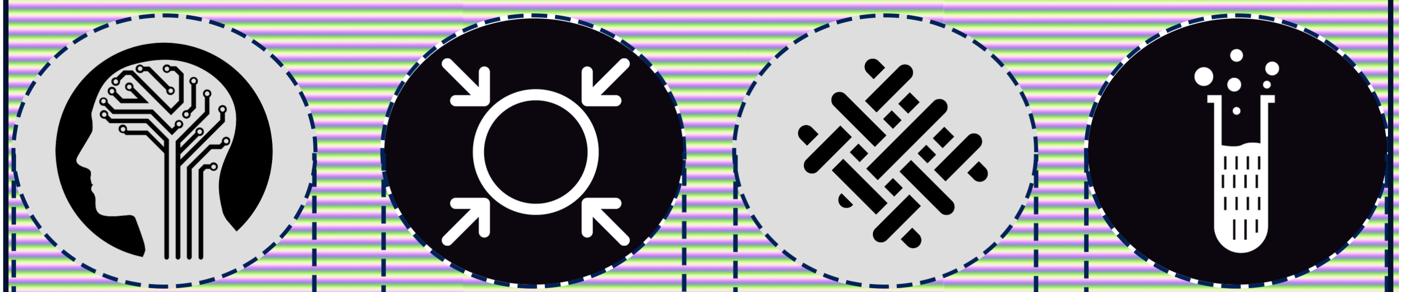


Figure. 0.1.3 Positioning the research questions and corresponding methods

0.1.4 Thesis Icons

The following key icons have been integrated within the respective chapter title pages to indicate the content and disciplines involved. The aim is to guide readers, demonstrating how the disciplines enter the thesis and correspond to one another at different stages.



Stroke Research
Encapsulates findings from literature reviews, anthropological enquiry and feedback with key stakeholders.

[Chapters one to five, seven and nine]

Inclusive Design
Indicates where inclusive design methods have been implemented within particular areas of the thesis.

[Chapters two to four, six, seven and nine]

Textile Practice
This includes technical textile investigations, research of textile structures, and parameters involved in the making of samples.

[Chapters three, four, six to nine]

Material Science
Indicates areas of research that involves material investigation, theoretical research and material characterisation.

[Chapters six and eight]

Figure. 0.1.4 Thesis Icons

METHODOLOGY

0.2.1 Epistemological and theoretical perspectives of the research

The contextual framework of this thesis is based on a mixed methods approach, forging methods of participatory design (Sanders and Stappers, 2008), design anthropology (Gatt and Ingold, 2016), within theories of constructivist grounded theory (Glaser and Strauss, 1967; Glaser, 1978; Strauss and Corbin, 1998), action research (Lewin, 1946) and Interpretive Phenomenological Analysis (Larkin et al., 2006). This framework (Figure 0.2.1) is considered beneficial to support the overarching inclusive design approach which places the researcher at the centre of stakeholder experience. The purpose of this is to critically analyse stigma, familiarity and degrees of normalcy, specifically within wearable technology and the use of a garment as a ‘platform for care’ that influences states of health and wellbeing.

Additionally, where material investigations require input from both user-centred and technical data to evaluate material choice, systematic approaches are included too (indicated as ‘Material Testing and Characterisation’ in Figure 0.2.1). Such systematic approaches seek to make early enquiries into the feasibility of using a particular component or material for intervening. This data is combined with data from user-centred studies. The aim of combining these sets of data is to position material evaluations from the user’s perspective within an everday context.

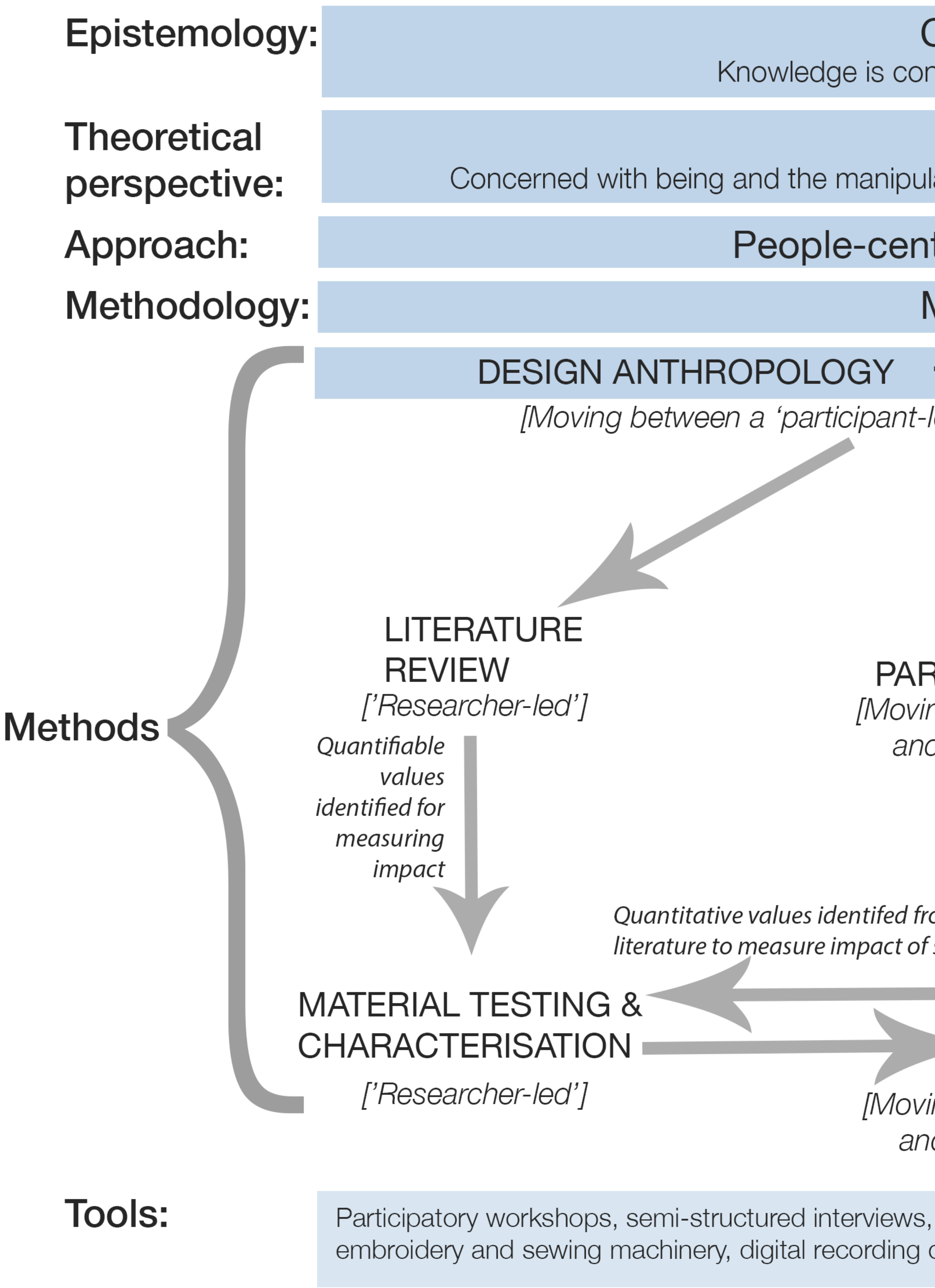
Since the thesis explores the opportunities and challenges for using garments as therapeutic devices, both technical and user-centred data hold pivotal points of information for evaluation. However, although technical calculations are included, the thesis retains a constructivist approach to material characterisation and testing. Experiments are guided by exploratory design methods rather than predictive values and extensive engineering requirements, which lay out of scope to explore rigorously. Albeit, Chapters five and nine include some data with indications for future work noted in Chapter ten.

A constructivist epistemology questions “invariant laws of nature, mere social hierarchies” (Jeffreys, 2017), placing an importance on accounts collected through anthropological studies of lived experiences and knowledge (from both users and researchers). Hence why the research moves between ‘participant-led’, ‘participation between’ and a ‘researcher-led’ focus (Figure 0.2.1).

An emphasis is placed on the voice of the participants from a ‘strategic essentialism’ perspective (Spivak, 1993). Underlying ideologies and social constructs may therefore raise ethical concerns; which were brought into conversation with the stakeholders

Chapters two and three).

The nature of the 'trans-disciplinary' work requires typical approaches to be re-thought and sometime values, the approach may sit more so in one particular field than another. Who or what guides this varie it means to 'be'. As such, the research takes a semantic focus to explore to what extent a quality of lif relevant chapters.



s merged. However, depending on the expertise of the researcher(s) involved and their epistemological es. This research is interested in unpacking what is important in ‘being’, ‘living’ and on some level, what e can be shaped. Where this Chapter introduces the methodology, additional details are included in the

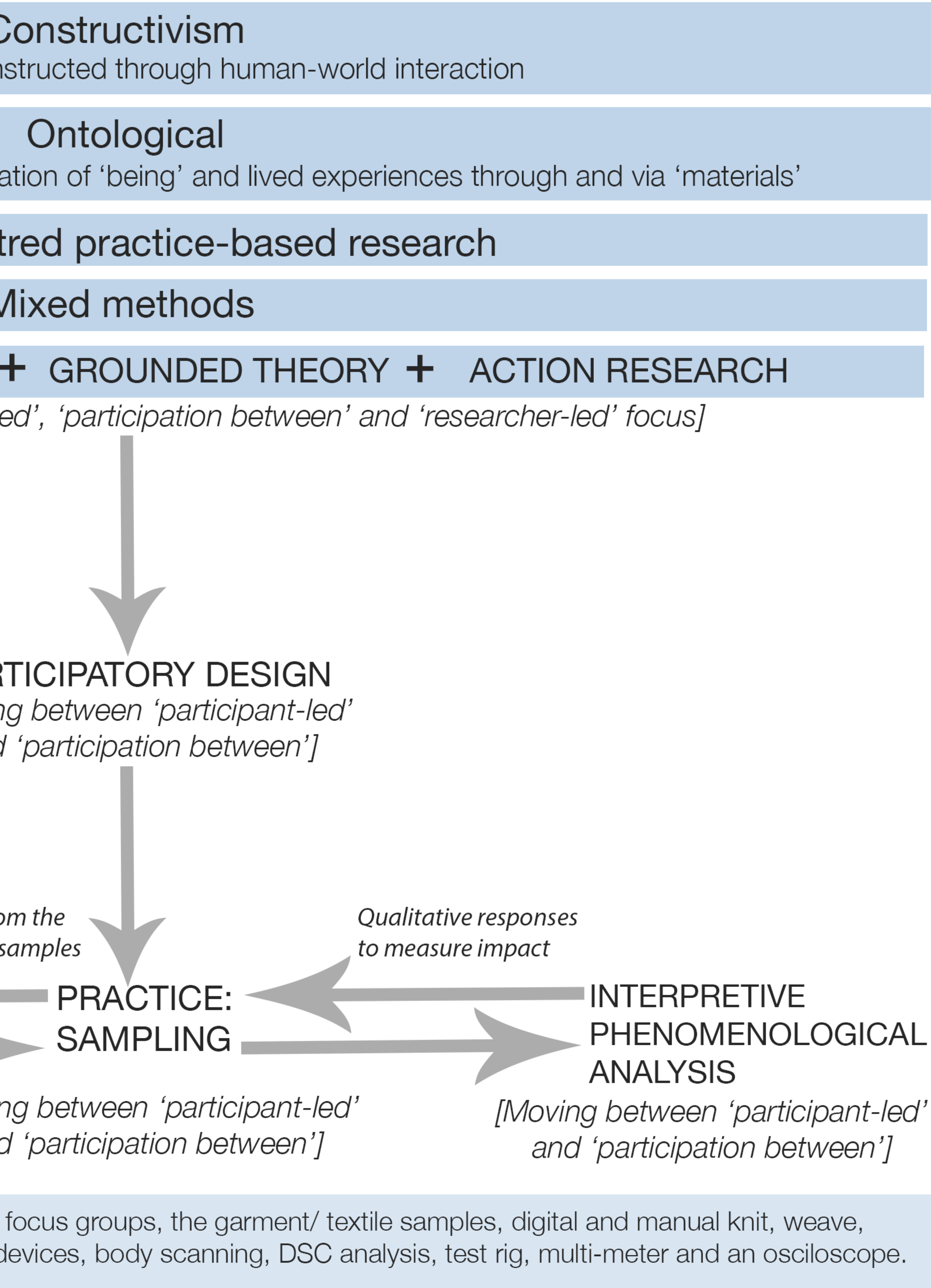


Figure. 0.2.1. The theoretical framework: An overview

0.2.2 Introducing the methodology

In the first instance, there exists a need to understand the lives of those who have had a stroke. Grounded theory appeals to this as a recognised method that seeks to construct theory about issues of importance in people's lives (Glaser and Strauss, 1967; Glaser, 1978; Strauss and Corbin, 1998); whilst also being used extensively in research focused on care, health and wellbeing (Boychuk and Morgan, 2004; Mills et al., 2006).

Grounded theory and design anthropology are brought together to articulate the dialogue between health, wellbeing and a sense of self post-stroke, with key stakeholders (Figure 0.2.2). Rather than seeking to prove or disprove preconceived ideas, a focus is placed on understanding issues of importance to participants via a constructivist approach (Charmaz, 2007). The perspectives of these individuals are highly valued both in the construction of the research questions, as well as in the development of the subsequent findings. The research therefore moves between a 'participant-led' focus, 'participation between' (i.e. where the researcher(s) and participants work together) and a responsive 'researcher-led' focus (Figure 0.2.1).

Colour coding of the font has been used to clearly differentiate between the participant's voice versus other key stakeholders throughout the thesis: *Green* indicates the stroke/ brain injury survivor themselves; *blue* indicates the voice of clinical staff (PTs, OTs, consultants) and stroke researchers; whereas ***dark blue*** indicates community support teams.

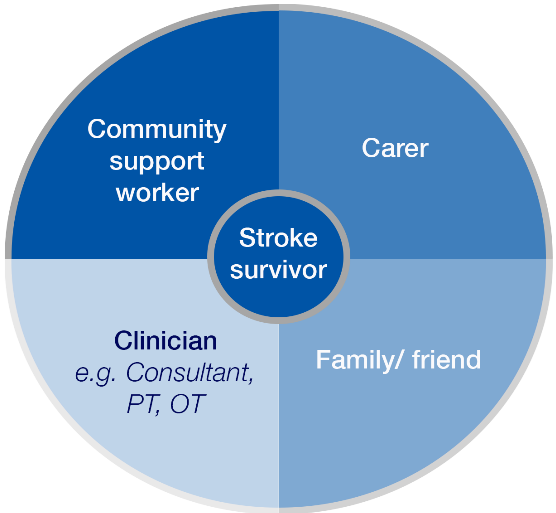
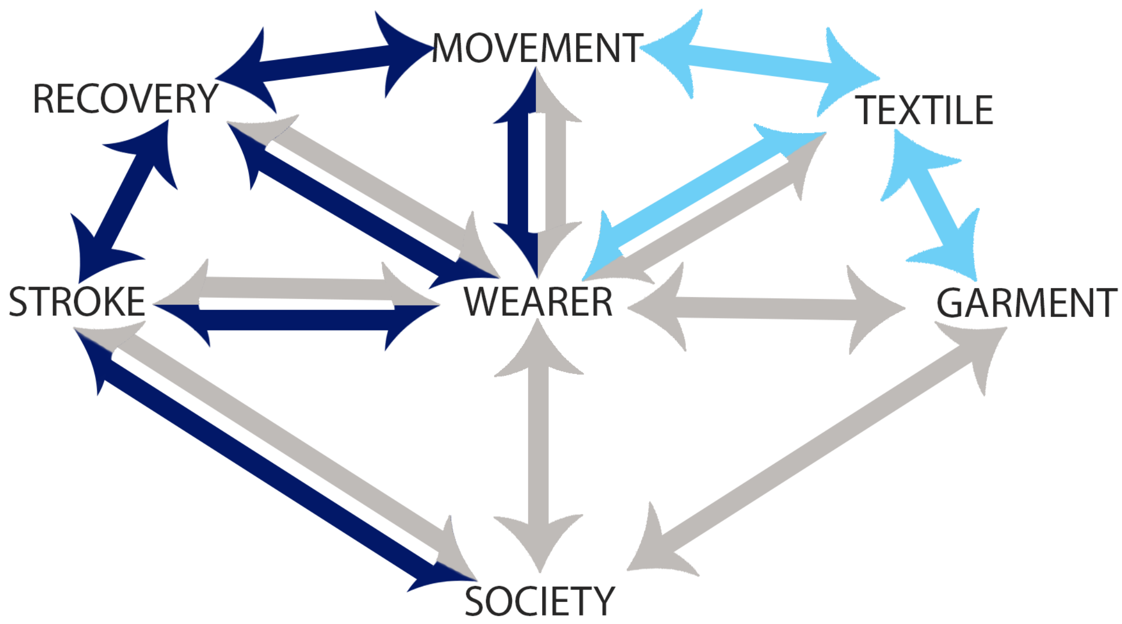


Figure. 0.2.2 Key stakeholders engaged in the research: Core - stroke survivor; Periphery - support network (carer, clinician etc.)



Key:

"Expert voice" *(e.g. Participatory workshops: participant discussions Focus groups: expert feedback/ observation/ video and voice recordings)*

"Researcher's research" *(e.g. Stroke literature/ clinical observation/ interviews and consultations with clinical experts/ volunteering/ Materials literature)*

"Researcher's interpretation" *(e.g. Material experimentation and sampling)*

Figure. 0.2.3 Graphical representation of the correspondence between areas of enquiry

The iterative nature of the research resembles action research models, commonly used within research for social impact (Lewin, 1946: 35). Moving beyond conventional scientific research models, the researcher is placed, at times, 'inside the action' (Figure 0.2.4). In the final stages of the research, a range of quantitative methods are sought in order to decipher the effectiveness of early samples. This is achieved via methods of material characterisation, including thermal analysis, and the construction of a test rig to determine the piezoelectric response of the samples. Chapter seven attempts to quantify degrees of softness by grading samples, enabling the researcher to position highly subjective experiences within contexts of sampling in the absence of the participants themselves.

Critically, for the research to have impact and be implemented in the real world it must be accessible, desirable and, in some cases, needed[1]. To design into this, it is necessary to not only understand the context in which the work sits[2], but to understand thoughts, feelings and therefore motivations for future behaviours via Interpretive Phenomenological Analysis (IPA).

[1] The focus is placed around the individual in a people-centred approach, rather than the disease itself.
[2] Unlike Derived Theory, the research is not entirely an interpretation of the stroke context, but a construction of real world experiences. The research is rather a depiction of collective lived experiences that are responded to by both the researcher and participants through reflective practice.

Where grounded theory is typically more concerned with understanding the parameters of the process/event itself, IPA was used to gain insight into what it was like for the individual (Larkin, Watts and Clifton, 2006), particularly in focus group settings, where the line of questioning was semi-structured.

The focus group attempts to draw upon participant's feelings associated with the samples and experiences whereby the participant responds to the researcher's response (samples) to the insights gathered. Unlike narrative analysis (Murray, 2000), participants' stories and life events enter conversation spontaneously, rather than in a linear fashion. Since the data is gathered over a sustained period of time, across varying locations (a mix of community and clinical settings paired with literature findings), data analysis occurs in parallel to data collection. Thematic analysis is used throughout the thesis to categorise findings and *"make sense of the data, and tell the reader what it does or might mean"* (Braun and Clarke, 2006: 94).

Figure. 0.2.4. Mapping the thesis on to the model of action research
(Adapted from Lewin, 1946)

0.2.3 Data gathering and analysis

0.2.3.1 Data collection methods

In the first instance, Design Anthropology (Gatt and Ingold, 2013; Ingold, 2018) is used to learn more about the stakeholders, from general conversations and simply 'being with' them in their lived environments. This persists throughout the research; requiring a reduced proportion in time as the research develops, but acting to consistently 'ground' the developments and enable cross-checking of the findings in the methods which follow.

It was important to understand lived experiences as they exist, with as little disruption as possible. Clinical observations and volunteer[3] positions provided insight into existing approaches to care within hospital and community contexts. Participatory design workshops were established within the community centre; an environment the participants often resided in, rather than in an alternative space, to minimise disruptions. Personal insights from ranges of key stakeholders are included via participatory design groups (Sanders, E. B. -N., 2002), exploring behavioural needs and lived experiences. This acts as a comparison to clinical recommendations, aligning human-centred needs contained within everyday life in the process. The 'participants' are seen as 'experts' in their own right, of their own 'lived experiences'; offering collective insights to the design process, expanding silos of 'expertise' originating solely from the designer(s)'/researcher(s)' vision, to that of a collective. Peer discussions move conversations from being about the self to, that which is for the collective, in comparing the self to others and considering how experiences may hold similarities and differences.

It is undeniable that in being human, researchers are part of the research endeavour, bringing with them a range of values and knowledge resulting from their sense of being (Heidegger, 1926). This holds influence on research outcomes (Guba & Lincoln, 1989; Appleton, 1997; de Laine, 1997; Stratton, 1997). The value of this correspondence, entanglement and presence of the researcher (Table 0.2.5) is utilised to understand others and their lived experiences.

More was learnt about the participants through raw, unstructured moments and conversations, contributing to building a level of trust in order to draw out further insights that may not have otherwise been disclosed. Anthropological findings enabled the researcher to intuitively analyse latter findings in line with the participant personalities and behaviour. However, in the later stages of the research, where participants were asked to make robust judgements on the focus of the research and the qualities of the samples, this level of relationship was considered unhelpful in so much as it would likely bias responses. A distance was maintained between participants and the focus of the research[4] to mitigate this (Chapter seven). Independent researchers were brought in to conduct the focus groups. Steps were also taken to engage new participants at later stages to refresh perspectives, reducing participant bias.

[3] For ethical reasons, no data was collected or documented as a volunteer, but used to simply inform and build up a body of knowledge that could be utilisied when responding to the insights.

[4] So that participants could not associate the work with the researcher.

Table 0.2.5: Role of the researcher and duration of research stages

Key
Stage 1a: Ongoing anthropological enquiry: observing and 'being with' participants a The Hackney Stroke Project, Shoreditch Trust, London ***[AE];***
Stage 1b: Ongoing anthropological enquiry: observing and 'being with' participants a Headway East London ***[AE];***
Stage 2: Clinical observations at the *National Hospital for Neurology and Neurosurge Queen Square, London* ***[CO];***
Stage 3: Outpatient service observations at Charing Cross Hospital, London ***[OSO];***
Stage 4: Participatory design group workshops at Headway East London ***[PD];***
Stage 5: Responsive sampling ***[RS]***;
Stage 6: Focus group at Headway East London and The Hackney Stroke Project, Shoreditch Trust, London ***[FG]***;
Stage 7: Material characterisation and performance tests ***[MC/T].***

0.2.3.2 The development of participatory approaches

Within participatory methods the garment is used as a theoretical tool for gathering further insights into body behaviour, image and identity post stroke. The primary purpose is to understand the nature of the correspondence between the wearer, garment, textile structure, society and, more specifically body behaviour post stroke and resulting needs for recovery (Figure 0.2.2).

The use of garments, toiles and textile samples fits broadly into the area of discursive design (Tharp and Tharp, n.d) and critical design (Dunne, 1999). The use of garments presently and previously worn by participants along with garments never worn or imagined to be worn *"encourage users' reflections upon, or [engage] with, a particular discourse"* (Tharp and Tharp, n.d). Whilst the development of toiles and textile samples provide a response to existing, experienced approaches to post-stroke care, demonstrating an alternative manner in which care may be deployed. In doing so, *"preconceptions and expectations [are challenged] provoking new ways of thinking about the object [the garment and post-stroke care], its use [or delivery], and the surrounding environment"* (Dunne, 1999).

Participatory workshops (Sanders, 2002; Sanders and Stappers, 2008) transition from learning about participants' lived experiences to 'working with' participants to design alternative futures. Rather than 'designing for', participants take an active role in the research process; known as co-design (Sanders and Stappers, 2008).

	Role of the researcher	*Duration (months)*
at	Observation and engagement with participants	36
at	Observation and engagement with participants	9
ery,	Observer	4
	Observation and engagement with individuals	3a=6; 3b=6
	Facilitator and engaging with participants	4a=7; 4b=5; 4c=6
	Practitioner and correspondence with other practitioners	5a=4; 5b=4; 5c=6
	Distanced - Independent researchers brought in to conduct focus groups	3 (per segment)
	Practitioner and correspondence with other practitioners	5

The element of co-learning as a primary aspect of action research (Gilmore et al., 1986: 161) moves from defining needs and desires into the development of considered responses and actions in the form of design practice. The garment is a key tool, as a design probe (Chapter three). Interaction between the garment and participants occurred in four ways:

i) Handling and experiencing samples;

ii) Creating samples;

iii) Through the act of dressing and wearer tests (Figure 0.2.6);

iv) Documenting responses and critique either via annotations (Figure 0.2.7), sketches or verbally; within group sessions or on a one-to-one basis.

Some individuals experience communication difficulties as a result of stroke (e.g. aphasia), limiting their engagement. Rather than excluding these individuals from participating, which is contrary to the values held by the research's inclusive approach, alternative methods[5] and additional support[6] was provided to include them. Activities were designed so that participation was not dependent on a particular medium.

[5]Participants were provided with appropriate tools for sketching, writing, typing and prototyping in addition to vocalising feedback.

[6] Support workers and carers were included to support participants with communication issues, e.g. helping to explain topics and support participants expressing their opinions in activities.

Figure. 0.2.6 Experiencing the garment as design probe: wearer tests (Author's archive)

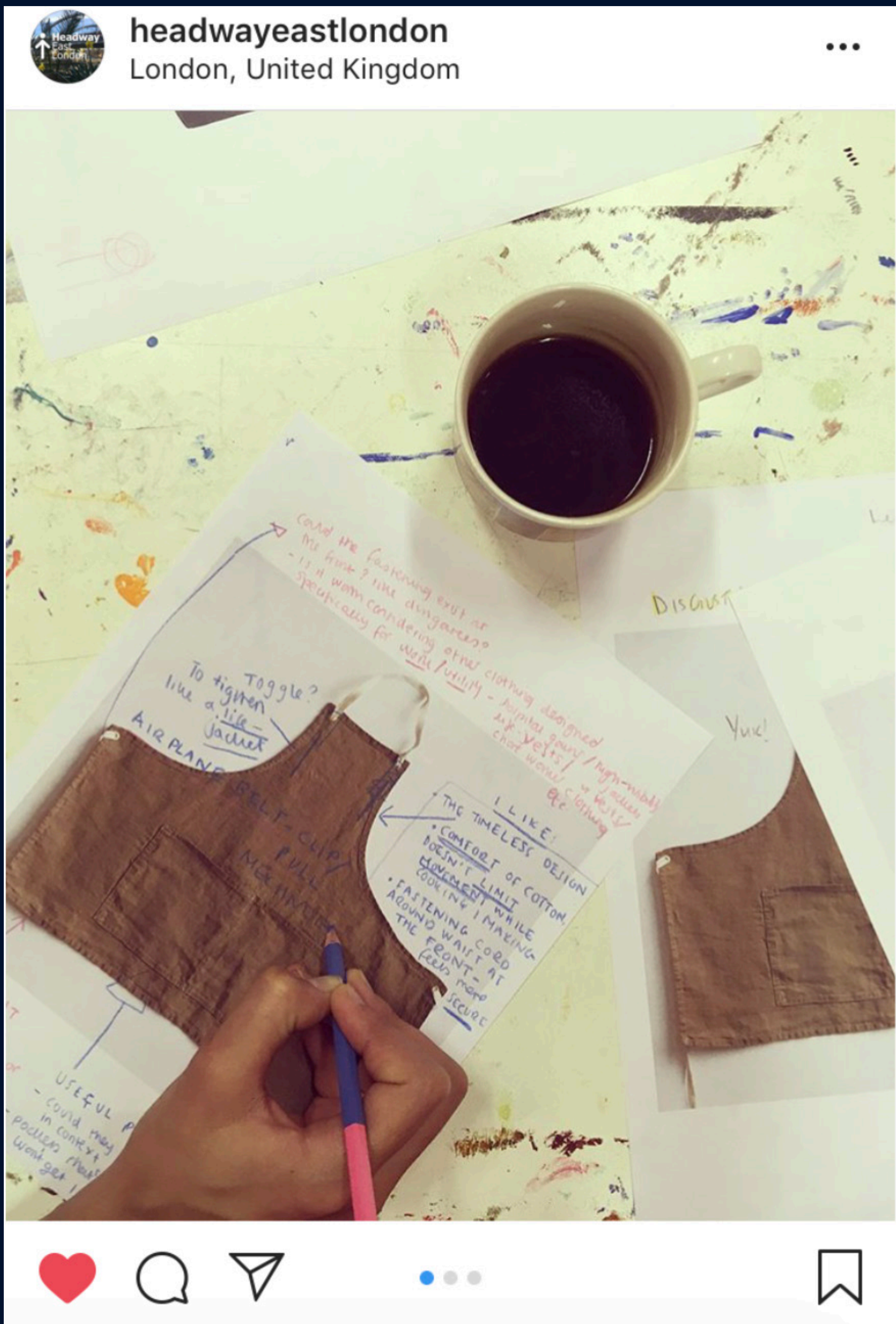


Figure. 0.2.7 The garment as a design probe: A participant annotating their response (Author's archive)

Upon establishing the hypothesis (Chapters five and six), a range of quantitative methods (material characterisation and focus group enquiries) were employed to analyse early experiments. Chapters seven to nine detail methods utilised, whilst Figure 0.2.8 demonstrates the relationship of participatory design to other methods, with pilot clinical trials considered as future work (Figure 10.3).

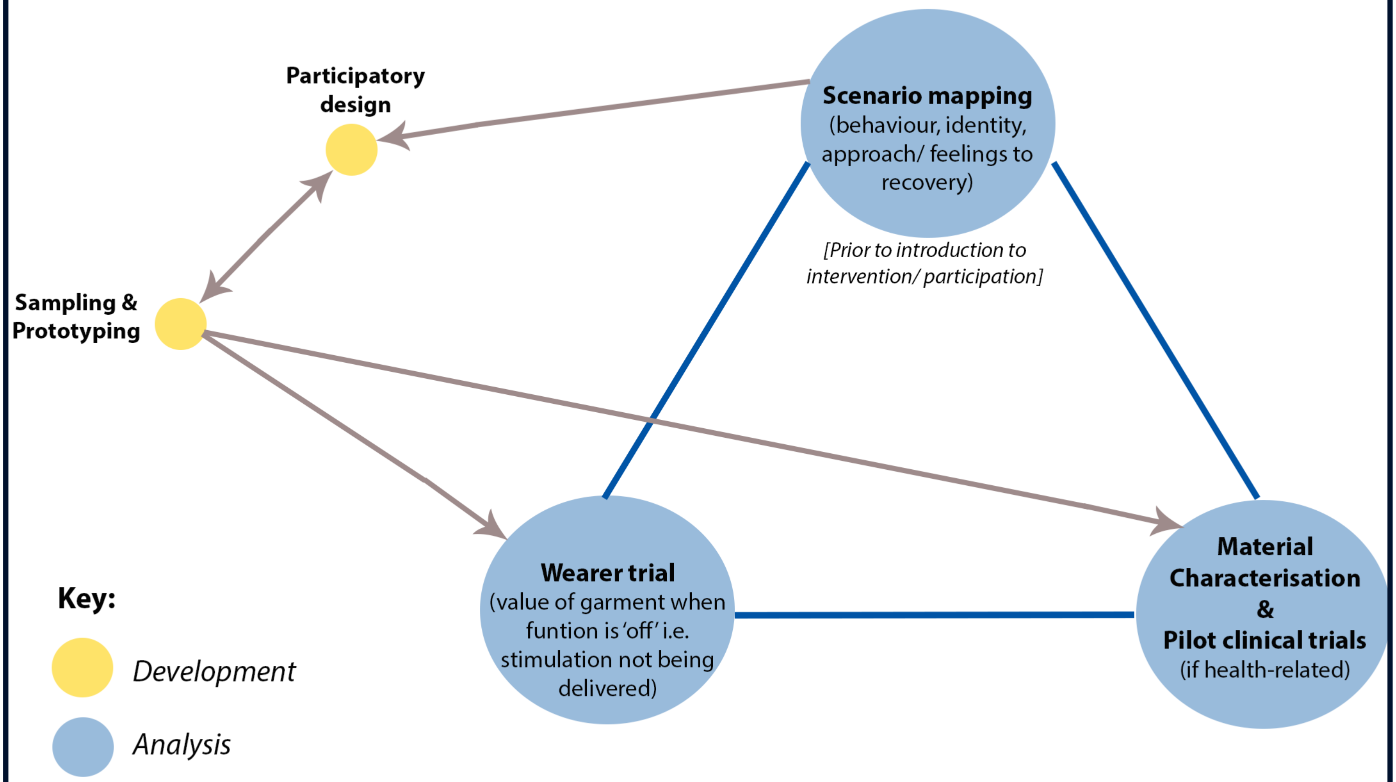


Figure. 0.2.8 Graphical representation of the correspondence between methods of development and analysis (Salisbury, Ozden-Yenigun and McGinley, n.d.)

Strategy for mitigating risk and handling difficult studies 0.2.4

Before proceeding with Chapter one, a consideration is made towards the risks and difficulties in conducting the research:

1- Ensuring there is rigour and reducing bias in data gathered

Where necessary, independent data collection methods and personnel are brought in. Data is combined from a variety of sources and comparative therapies. Consultations with key experts identified through the literature (Baker, 2020), at key conferences (Stockley, 2020) and informal discussions with stroke consultants (Ward et al., 2018), OTs and PTs (ULP:d, 2018; ULP:p, 2018) during clinical observation and within the community, provided the opportunity to cross-check data gathered in line with current and emerging research and practice.

2- Enabling participation and support for recruitment of participant groups

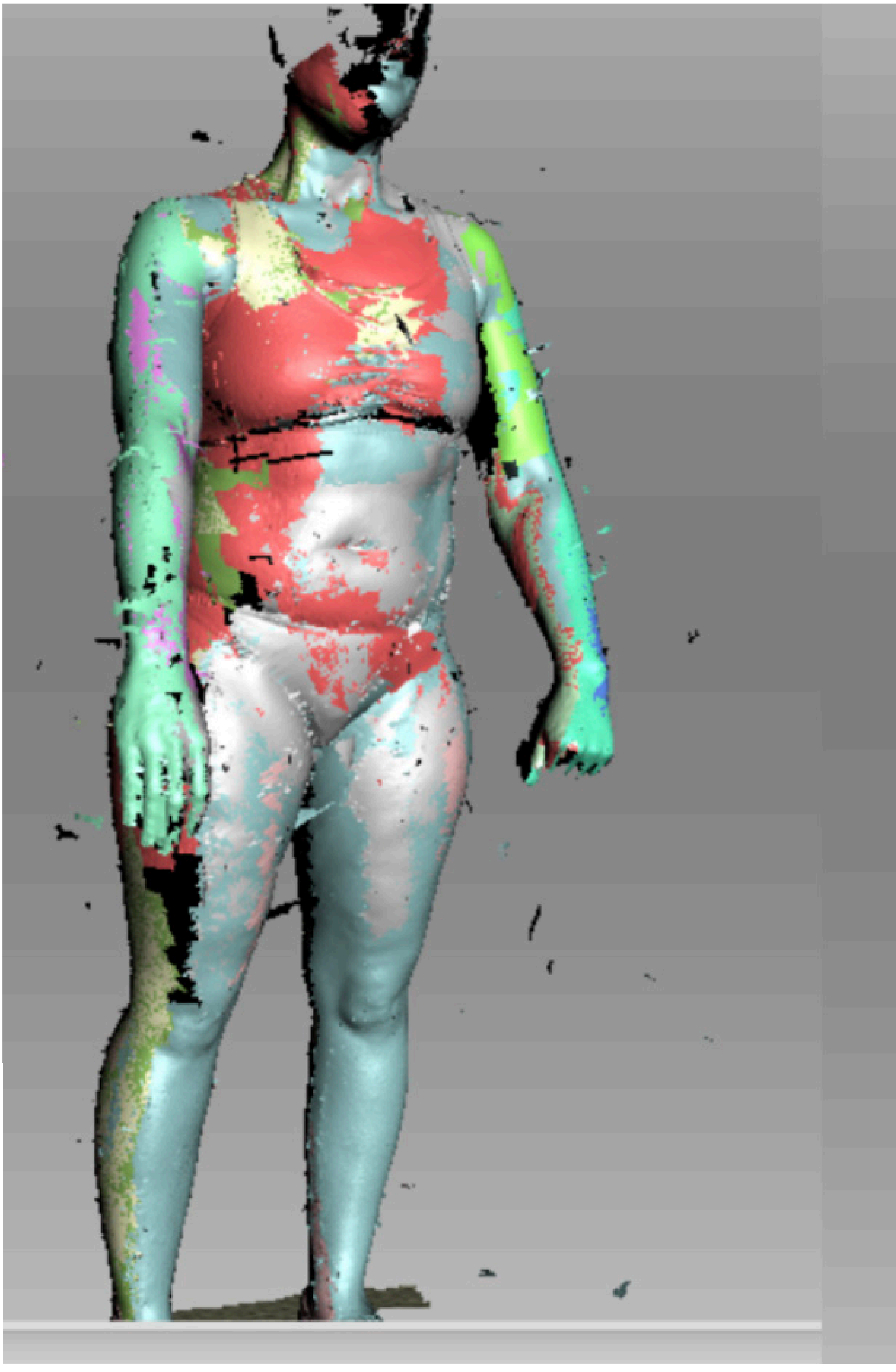
Participatory methods are adapted in order to work closely with support workers, friends and families of those who do not typically participate in support groups and/ or rehabilitation. Partnerships with stroke and brain injury charities supports the recruitment of participants.

3- Developing and testing samples

Since there exists no suitable equipment within the RCA to complete sample development of the nanofibers, the research partnered with Alrai at Istanbul Technical University so that the samples could be realised. This was supported by a grant from Research England via the MedTech SuperConnector [Grant number: CCF07-3270] enabling the purchase of key equipment.

Body scanning (Figure 0.2.9) was used to visualise upper limb post-stroke ranges of movement. A grant from the Design Research Society made it possible to pursue this. Only one participant was scanned since this study was not aiming to quantify or produce vast data, rather to utilise the body scan to support the communication of the research via diagrammatic methods. Later on in the research the body scan was converted into a bespoke mannequin (Chapter nine), supporting development of the fit and positioning of the garment and bead respectively.

Further access to equipment was required to conduct analysis on yarn specimens produced in Chapter eight. Funding from the Henry Royce Institute’s Equipment Access Scheme [Grant number: EP/R00661X/1] enabled testing to be carried out.



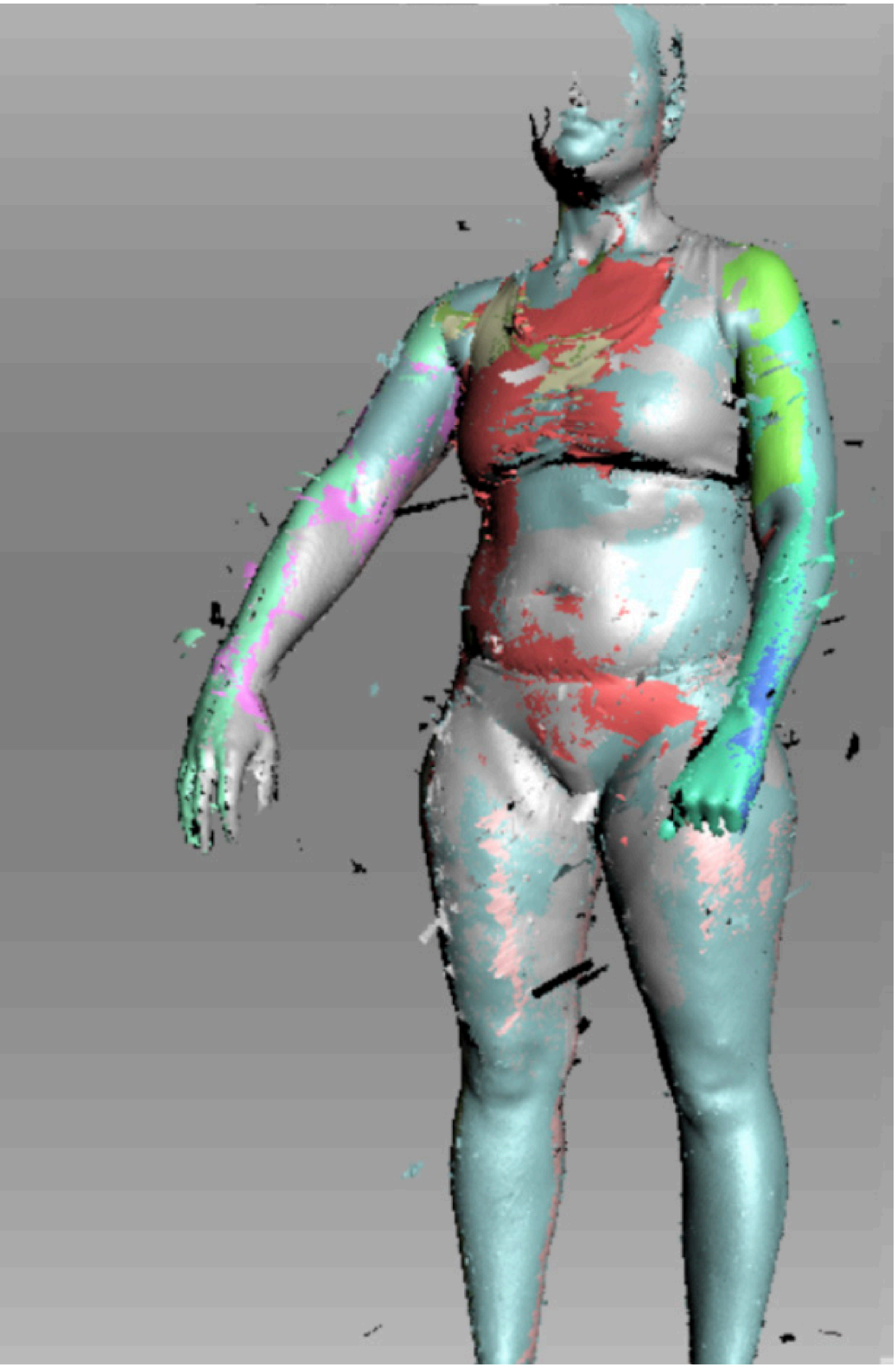


Figure. 0.2.9 ‘Under Development’: Visualising the body post stroke via body scanning
A visual of early scan data and QR codes displaying clips of two upper limb positions.
(Author’s archive)

CHAPTER 1.0

Positioning the reader: Establishing the need of the research

1.1 A critique of current practice

1.1.1 Approach

The purpose of this chapter is to establish an understanding of the context within which the research sits. As stated in Chapter 0.2, the first phase of the research aims to better understand the research space via ongoing anthropological enquiry (Table 0.2.5) and literature review.

In this thesis a focus is placed on stroke which remains the central theme to each case study exploring how rehabilitation may be integrated into garments and textiles (see case studies one to three in Chapter four and case study four in Chapters five to nine). Therefore the aim of this chapter is to contextualise current approaches to treating upper limb hemiparesis within the wider system of stroke care. Information is collated from:

i) A 25-month anthropological case study conducted with key stakeholders (Figure B2 in methodology) in local London community boroughs[1];

ii) Clinical observations of Professor Nick Ward and team's specialist Upper Limb Programme[2] [3];

iii) Consultations with additional stroke specialists: Professor Stuart Baker, Dr Rachel Stockley and Dr Alex Luff;

iv) Information gathered from attending UCL Partners Seminars;

v) Key stroke workshops including the NIHR UK Stroke Research Workshop (approved by the Royal College of Physicians) at Cambridge University in 2018[1].

Additionally, stakeholder feedback and correspondence with stroke specialists provides an understanding of lived experiences beyond reported impacts from stroke literature.

The data was analysed for issues pertaining to upper limb rehabilitation from the perspective of key stakeholders, taking into account social and cultural factors that may come to influence the course of recovery; which become detailed further within Chapters two and three.

Consent forms[4] were used to document consent given by participants and responses were coded via thematic analysis (Braun and Clarke, 2006) to group and filter vast amounts of data. The data collected was thematically categorised within the following overarching

[1] Anonymised tables of supplementary participant data, certificates of involvement and approval for clinical observations are located in Appendices 3.1, 3.2 and 3.3 respectively.

[2] Headway East London [spans 11 east London boroughs] and The Stroke Project [part of Shoreditch Trust].

[3] The hospital for Neurology and Neurosurgery at Queen Square, London.

[4] See Appendix 3.4

themes: ‘Immediate Care’[5] (Section 1.2), ‘Early Rehabilitation’[6] (Section 1.3) and ‘Post Discharge’[7] (Section 1.4).

Key diagrams (Figures 1.1, 1.5 and 1.8) have been constructed to summarise the patient pathway; developed in consultation with stroke survivors, clinicians and supplemented by data from Cochrane, SSNAP and Royal College of Physicians reports, all dated within the last five years.

1.1.2 Limitations and key considerations of the literature

It should be noted that there exists several limitations in the analysis of current methods:

i. Variations in the availability of resources which differs across geographical locations, even from borough to borough within community services.

ii. Clinical practice uses certain methods which are based on clinical knowledge and experience held by the therapist. Whilst reporting guidelines like the ‘TIDieR’ (Template for Intervention Description and Replication) checklist (Hoffmann et al., 2014) are increasingly used by studies which provide more detailed descriptions of treatments in trials, the evaluation of rehabilitation in stroke is seen to use poor reporting procedures. General terms, e.g. ‘standard therapy’ (Lohse et al., 2018) can include any number of combinations of approaches which fail to be rigorously defined within the literature (Stockley et al., 2019). This makes it difficult *“to determine how well research evidence is being translated into routine practice and informs therapy provision”* (ibid), as well as identifying and comparing existing and newly proposed methods.

iii. Wide ranges of comorbidities and disabilities resulting from stroke further complicate the ability to compare methods, since approaches of care are individualised.

iv. Variations in assessment types, measures used by therapists, and outcome tools used to classify arm function can make it more difficult to comparatively analyse studies (Persson et al., 2012; Stinear et al., 2017). It is often unclear whether a test is chosen based on cost, knowledge of being able to perform that test, or of relying on a test that they have always done. In the majority of cases tests are not conducted on reliability or validity, presenting major issues during data interpretation (ibid; Drummond, 2020).

v. In some cases (e.g. Lang et al., 2016; Rodgers et al., 2019), outcome measures may be incorrectly used: for example where negative symptom interventions use positive symptom outcome measures (Krakauer, 2018).

vi. There exists a need for more longitudinal research since, in some studies, there can be a reliance on data which is no longer applicable to current systems, length of hospital stay, methods of care and demography, to name a few (Drummond, 2020).

vii. There are limited datasets and an understanding of ‘life after stroke’ (Drummond, 2020) or activities performed outside of therapy sessions (Stockley et al., 2019). The majority of data exists within the first six to twelve months post-stroke (Drummond, 2020). Research observations mainly include the intensity, number of repetitions and time given to training within therapy sessions (De Wit et al., 2005; Bernhardt et al., 2008; Lang et al., 2009; Kimberley et al., 2010; Sjohom et al., 2014; Serrada et al., 2016).

viii. Finally, there is a limited focus on the negative symptoms in human trials. Animal models often focus on the negative symptoms[8], whereas there exists an emphasis on the positive symptoms[8] in humans (Krakauer, 2018).

[5] Care provided up until the delivery of rehabilitation within hospital
[6] Hospital rehabilitative care and care received in rehab centres upon immediate admission from Acute Care Unit (ACU) and Hyper Acute Care Unit (HACU).
[7] At home and community rehabilitation, specialist rehabilitation centres attended after returning home, along with the process of discharge.
[8] See Glossary

1.2 Immediate Care

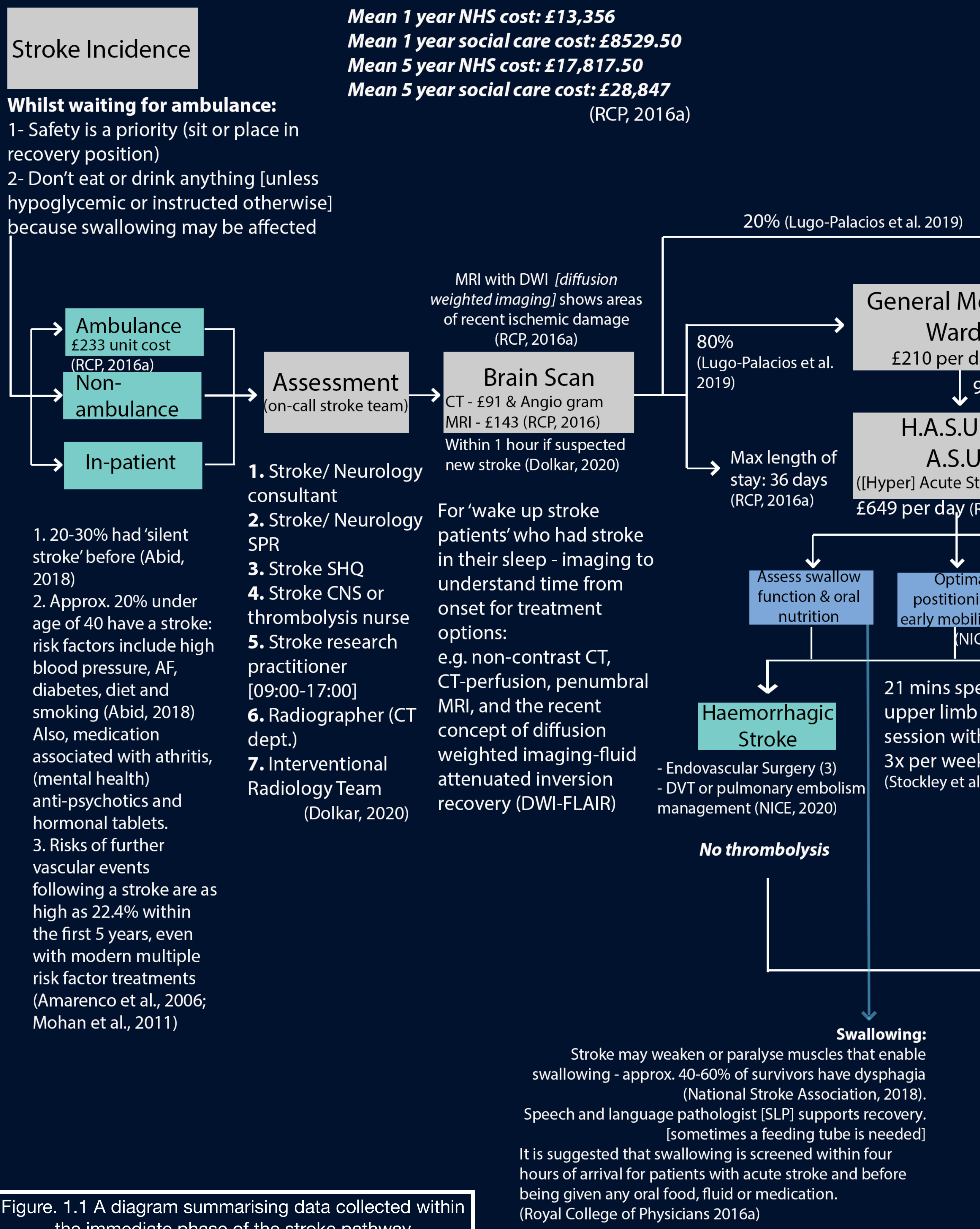
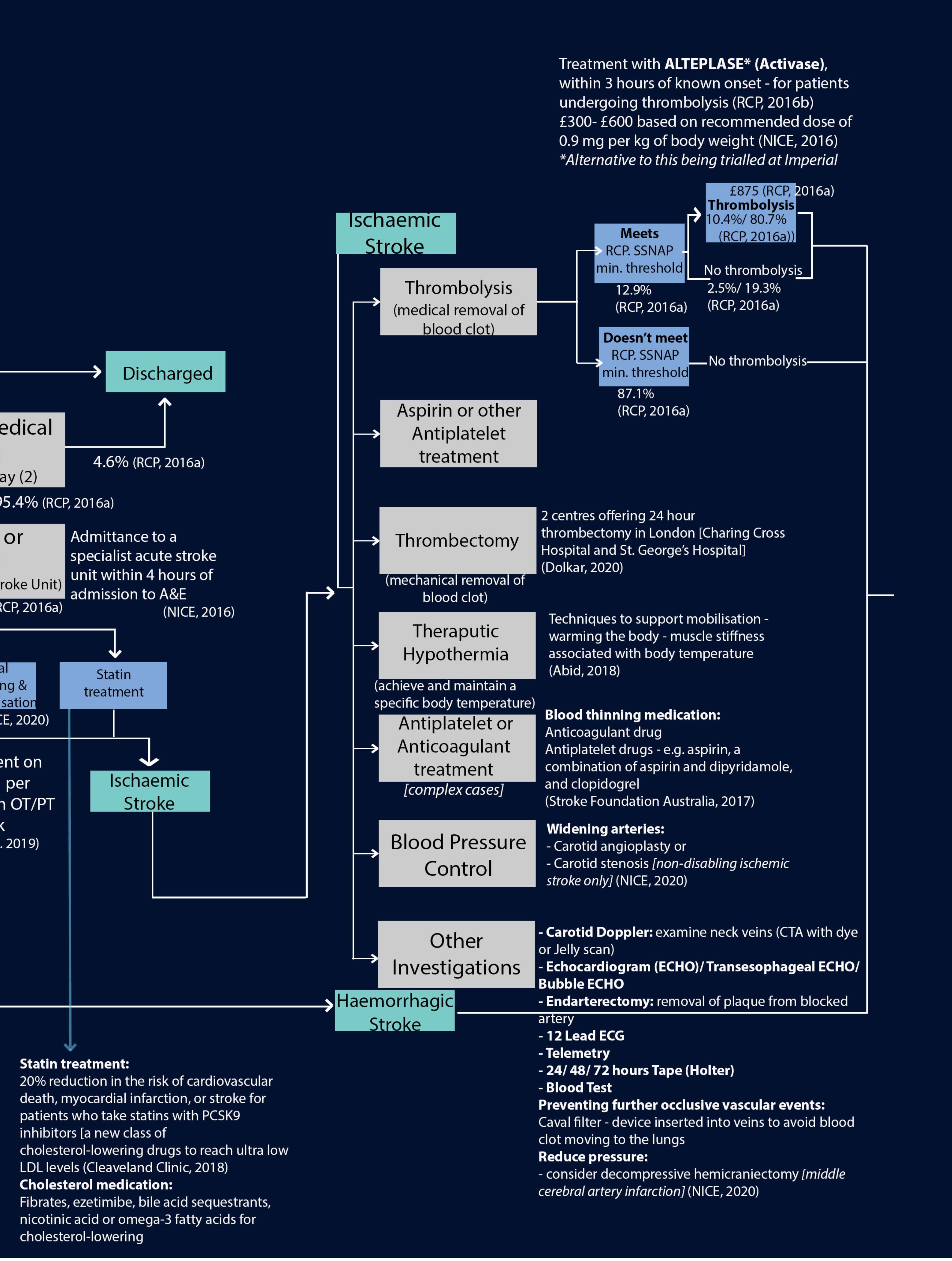


Figure. 1.1 A diagram summarising data collected within the immediate phase of the stroke pathway



Treatment with ALTEPLASE* (Activase), within 3 hours of known onset - for patients undergoing thrombolysis (RCP, 2016b)
£300- £600 based on recommended dose of 0.9 mg per kg of body weight (NICE, 2016)
*Alternative to this being trialled at Imperial
£875 (RCP, 2016a)
Thrombolysis
10.4%/ 80.7%
(RCP, 2016a))
Meets
RCP. SSNAP
min. threshold
12.9%
(RCP, 2016a)
No thrombolysis
2.5%/ 19.3%
(RCP, 2016a)
Doesn't meet
RCP. SSNAP
min. threshold
87.1%
(RCP, 2016a)
No thrombolysis
Ischaemic Stroke
Thrombolysis
(medical removal of blood clot)
Discharged
edical
ay (2)
4.6% (RCP, 2016a)
95.4% (RCP, 2016a)
Aspirin or other Antiplatelet treatment
or
roke Unit)
RCP, 2016a)
Admittance to a specialist acute stroke unit within 4 hours of admission to A&E
(NICE, 2016)
Thrombectomy
(mechanical removal of blood clot)
2 centres offering 24 hour thrombectomy in London [Charing Cross Hospital and St. George's Hospital]
(Dolkar, 2020)
al
ng &
isation
CE, 2020)
Statin treatment
Theraputic Hypothermia
(achieve and maintain a specific body temperature)
Techniques to support mobilisation - warming the body - muscle stiffness associated with body temperature
(Abid, 2018)
ent on
per
n OT/PT
k
. 2019)
Ischaemic Stroke
Antiplatelet or Anticoagulant treatment
[complex cases]
Blood thinning medication:
Anticoagulant drug
Antiplatelet drugs - e.g. aspirin, a combination of aspirin and dipyridamole, and clopidogrel
(Stroke Foundation Australia, 2017)
Blood Pressure Control
Widening arteries:
- Carotid angioplasty or
- Carotid stenosis [non-disabling ischemic stroke only] (NICE, 2020)
Other Investigations
- Carotid Doppler: examine neck veins (CTA with dye or Jelly scan)
- Echocardiogram (ECHO)/ Transesophageal ECHO/ Bubble ECHO
- Endarterectomy: removal of plaque from blocked artery
- 12 Lead ECG
- Telemetry
- 24/ 48/ 72 hours Tape (Holter)
- Blood Test
Preventing further occlusive vascular events:
Caval filter - device inserted into veins to avoid blood clot moving to the lungs
Reduce pressure:
- consider decompressive hemicraniectomy [middle cerebral artery infarction] (NICE, 2020)
Haemorrhagic Stroke
Statin treatment:
20% reduction in the risk of cardiovascular death, myocardial infarction, or stroke for patients who take statins with PCSK9 inhibitors [a new class of cholesterol-lowering drugs to reach ultra low LDL levels (Cleaveland Clinic, 2018)
Cholesterol medication:
Fibrates, ezetimibe, bile acid sequestrants, nicotinic acid or omega-3 fatty acids for cholesterol-lowering

1.2.1 Initial support

"Improvements in acute medical care mean that more people are surviving than ever before, but may need significant rehabilitation to restore function" (Stockley et al., 2019). However, methods such as thrombolysis have contributed to preventing greater levels of disability. Although, the percentage of individuals who receive this is relatively low (Figure 1.1); with issues often relating to transportation/distance from specialised centres with thrombolysis and thrombectomy set ups (ULP:d, 2018) and the availability of trained staff. *"Navigating the catheter can cause serious complications if not done correctly. Extending the catheter forward can cause a dissection and tear off parts of the vessel causing further blockage and more extensive brain damage"* (CO, 2019). To boost access the integrated stroke delivery network has established plans to expand thrombectomy centres to have full geographical coverage and streamlined imaging within 72 hours, with thrombolysis having streamlined pathways with 24/7 coverage by 2024.

However, individuals may struggle to spot the signs of stroke in time to access immediate treatment and help if they are alone when the stroke occurs: *"I was alone when I had my stroke. No one knew and I was left on the floor for days until they found me"* (FF, 2019). In response to this campaigns (e.g. FAST) help generate awareness, albeit not comprehensively enough in some cases (Bietzk et al., 2012; Robinson et al., 2013).

Once admitted to an ACU or HACU, the approach to care tends to be *"mostly passive"* (CO, 2019), emphasising prevention of secondary co-impairments such as contractures, pressure ulcers and deconditioning (Brandstater and Shutter, 2002). A focus is placed on methods to prevent further strokes. Preventative methods also exist prior to this stage of need for those in particularly vulnerable categories; e.g. the administration of anticoagulation treatment to sufferers of Atrial Fibrillation (AF) have been successfully reported in recent years (UCL Partners, 2020). Future plans aim to deliver a "seven day service including therapy" with improved primary and secondary prevention, AF detection and blood pressure (BP) management (ibid).

There remains key issues in regards to the acute care set-up which hold significant impacts on recovery. Whilst it is suggested that 'most patients' should spend the majority of their inpatient stay on either an ACU or rehabilitation stroke unit, observational studies mapping patient isolation in hospitals following a stroke conducted in 2005 (De Wit et al.) and again in May 2017 (Chouliara et al.), found that patients spend around a third of their day sleeping and lying with no activity. A trainee consultant suggests there are limits in what can be achieved in the ward: *"The wards aren't set up well for rehabilitation. There's often a separate room for that, however, this can be difficult to access, particularly for those with more severe mobility deficits"* (CO, 2019).

1.2.2 Early mobilisation

Regular mobilisation of the upper limb is required to avoid joint contracture (Zaaimi et al., 2012). Current guidelines advise early mobilisation (RCP, 2016a), which typically refers to providing support for getting up and out of bed. For patients who require little to no assistance this is expected to occur within 24 hours of onset. For patients who are medically stable but have difficulty moving without assistance, short daily mobilisations (sitting out of bed, standing or walking) with trained staff and access to appropriate equipment should begin between 24 and 48 hours of admission. Intermittent pneumatic compression within 3 days of admission to hospital should be offered to immobile patients for the prevention of deep vein thrombosis, with continuous treatment until the patient is mobile or discharged (RCP, 2016a).

The 2016 stroke audit (RCP, 2016a) also calls for investment in resources within particular areas of the acute pathway to deliver better outcomes in the long-term; indicating the benefit of focusing earlier in the patient pathway to reduce overall demand of long-term social care (ibid). In cases where participating in rehabilitation is not possible, support for maintaining movement in the limb should be offered (ibid). However, implementing rehabilitation at this point is often restricted by the set-up of the acute care environment: *"Acute wards are focused on getting people out of hospital so the value of mobility is considered to a greater extent"* (ULP:d, 2018).

There also exists global debates as to when rehabilitation should begin. Australian guidelines recommend that rehabilitation should start at the earliest possible point in time, ideally on the first day following a stroke; based on the World Health Organisation International Classification of Functioning, Disability and Health model (WHO, 2021). An update of these guidelines states that: *"starting intensive out-of-bed activities within 24 hours of stroke onset is not recommended"* (Bernhardt et al., 2015); rather suggesting *"frequent, short sessions of out-of-bed activity"* for those with mild to moderate stroke. The optimal timing within the 48-hour post-stroke time period is however, unclear (Bernhardt et al., 2015).

Questions surround the presence of a hyper-plastic state; which allows for greater amounts of spontaneous recovery and responsiveness to therapy strategies, including the use of appropriate interventions to facilitate the pre-existing architecture which remains (i.e. the use of intact neural pathways). Krakauer suggests that this *"window of opportunity"* is very short (although recovery is still possible in the chronic stages: Ward et al., 2019); lasting approximately four weeks from the infliction of infarct (Figure 1.2).

Current rehabilitation so far is not seen to be able to influence the extension of recovery residing from this 'window' (Krakauer, 2018), although significant studies (Biernaskie et al., 2004; Zeiler et al., 2016) report the benefit of implementing rehabilitation at early stages. In identifying a postischemic sensitive period, a correlation between increased levels of recovery and earlier re-training was demonstrated. Figure 1.3 (Biernaskie et al., 2004) shows that, by initiating training at just five days post-stroke (point a on the graph on the right of Figure 1.3), in direct comparison to initiating enriched rehabilitation at fourteen or even thirty days post-stroke (point b), a correlation to improved recovery is observed (points aa and bb on the left graph, respectively). Zeiler et al. (2016), was able to reinforce these findings by inducing a second stroke, reviewing findings in the same 'body' (Figure 1.4). They reported that after training was initiated eight days post-stroke; point w on Figure 1.4), recovery was seen to reach around 37% (point x). Yet when training was initiated just 48 hours[9] post a second induced stroke (point y) in the same rodents, recovery could be seen to reach approximately 50% (point z on Figure 1.4).

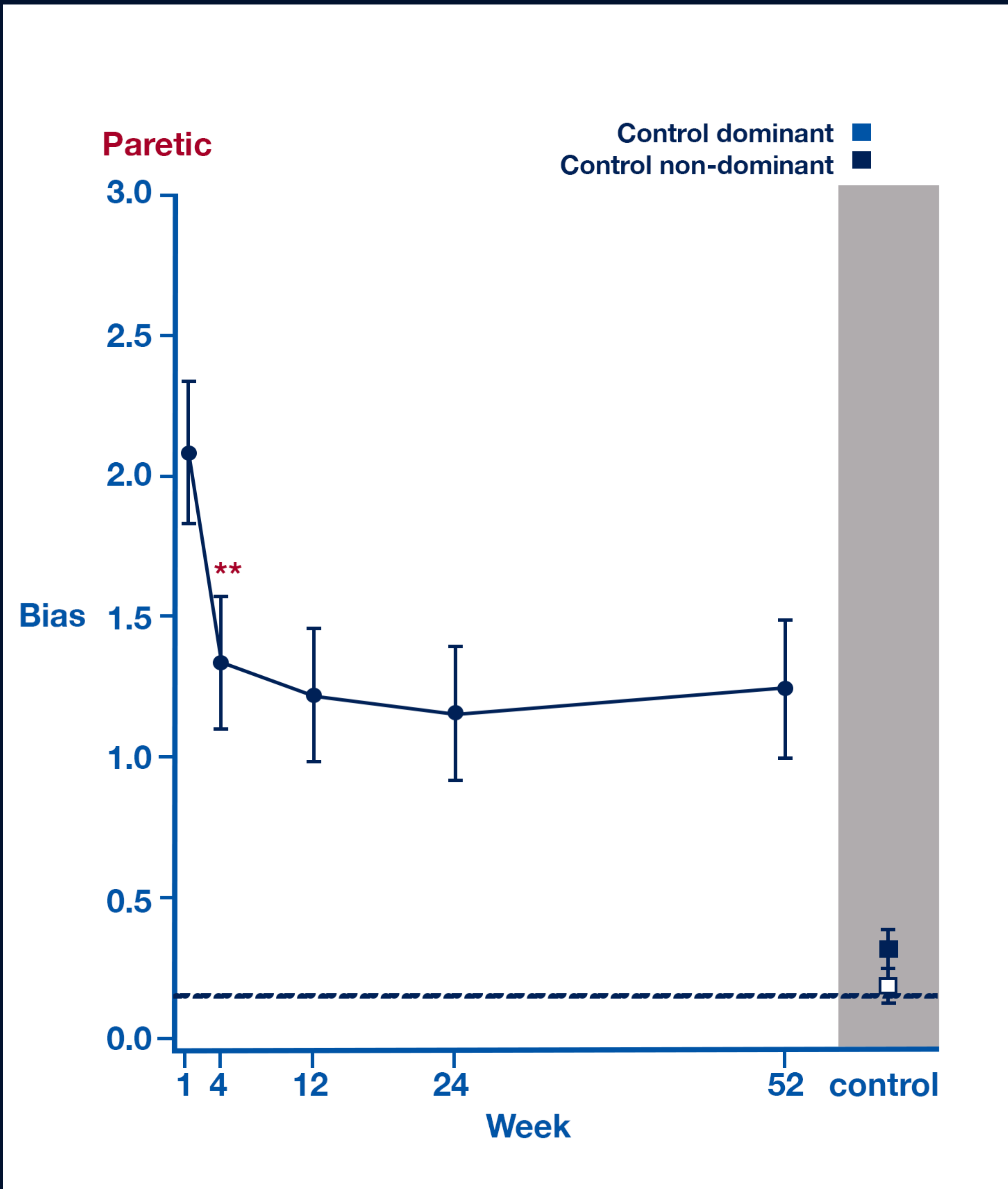


Figure. 1.2 The spontaneous recovery of motor control of the upper limb (Krakauer, 2018)

There exists many barriers to participating in rehabilitation, particularly at such an early stage. Individuals report struggling in coming to terms with having had a stroke and understanding the consequences of it: *"At first I didn't know what was happening, who I was, anything. You need someone who's been through that to help talk to you"* (EE, 2018). This has a direct impact on recovery (Jensch, 2017) by making it difficult to involve individuals within rehabilitation at early stages when these feelings may be initially heightened. *"Some people just shut down. There was a gentleman in a bed near to me who looked into having his arm removed because it was like an anchor to him"* (FF, 2019). Approximately a third of stroke survivors are reported to have some sort of emotional problem, yet there is little focus placed on asking people how they are feeling (Jensch, 2017). Jensch goes on to say that individuals often report a sense of strong emotion linked to their stroke; be that fear, powerlessness, and/or loneliness. This likely influences early participation.

Yet, considerations for early intense rehabilitation [specifically concerning electrical stimulation methods (Humm et al., 1999)] are met with objection for fear of exacerbating lesion volume resulting in declining behavioural outcomes[9] (Krakauer and Carmichael, 2017; Cortes and Krakauer, 2018). Current data still suggests that increases in neuronal activity or behavioural activity for between three to five days post-stroke can lead to increased damage (Clarkson et al., 2010; Clarkson et al., 2011). It remains unclear whether the use of alternative stimuli within this period would contribute to the same effects, although it is considered that due to the level of neuronal activity generated by such approaches, that it likely will.

[9] Adverse effects were observed following an electrolytic lesion and immobilisation of the unaffected limb to promote intense use of the affected limb in rodent studies (Kozlowski et al., 1996; Humm et al., 1998). Effects of increased infarct volume were not observed following the infliction of ischemic lesions of a middle cerebral artery occlusion whereas declining behavioural performances were (Bland et al., 2001).

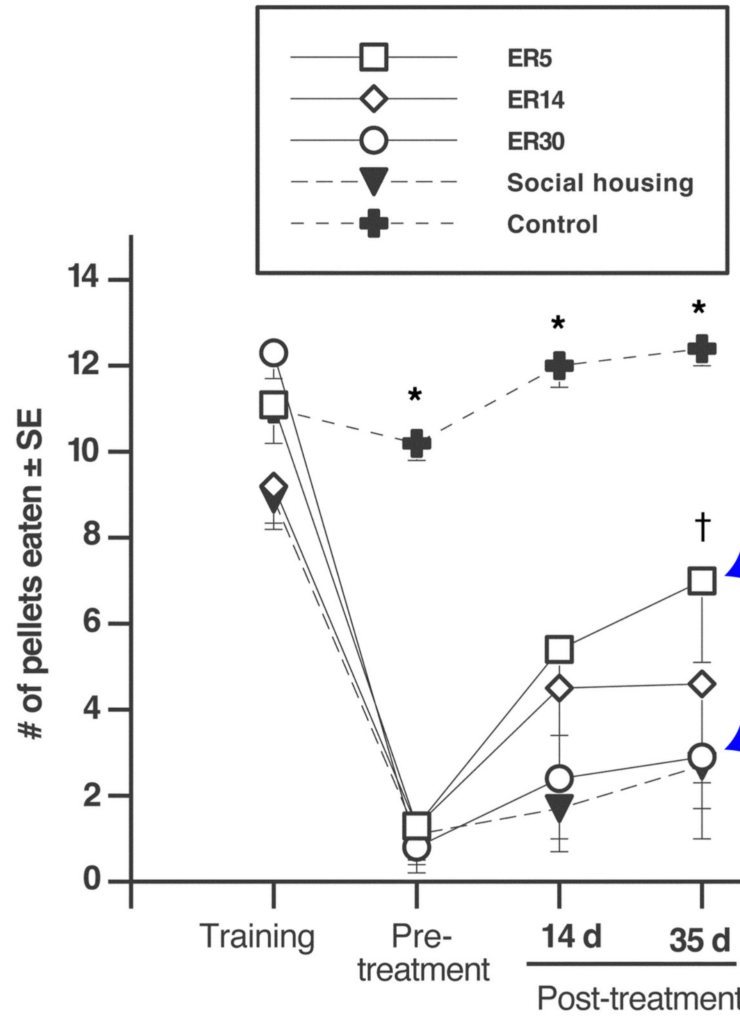
Figure. 1.3 Benefits of implementing rehabilitation at early stages of recovery
(Adapted from Biernaskie et al., 2004)

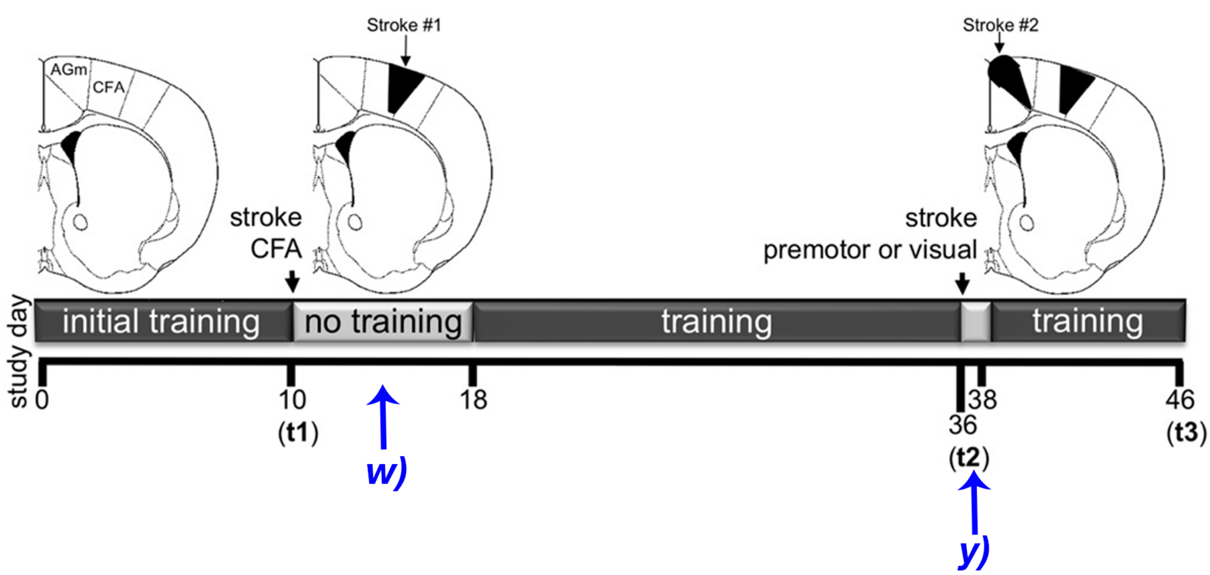
Left:
"Staircase reaching test. The mean number of pellets eaten from the staircase below the impaired limb is shown [...] ER5 animals were able to retrieve more pellets than socially housed animals [and] showed a strong trend for improvement relative to ER30 animals (p = 0.07). ER5, n = 8; ER14, n = 7; ER30, n = 7; social housing, n = 6; controls, n = 9" (ibid).*

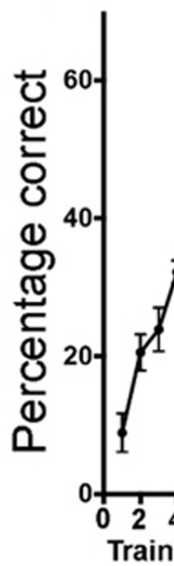
Middle:
"Dendritic branching in the undamaged motor cortex [...] ER5 elevated the number of higher-order branches relative to all other groups [...] early rehabilitation enhanced the dendritic branch number relative to delayed ER" (ibid).

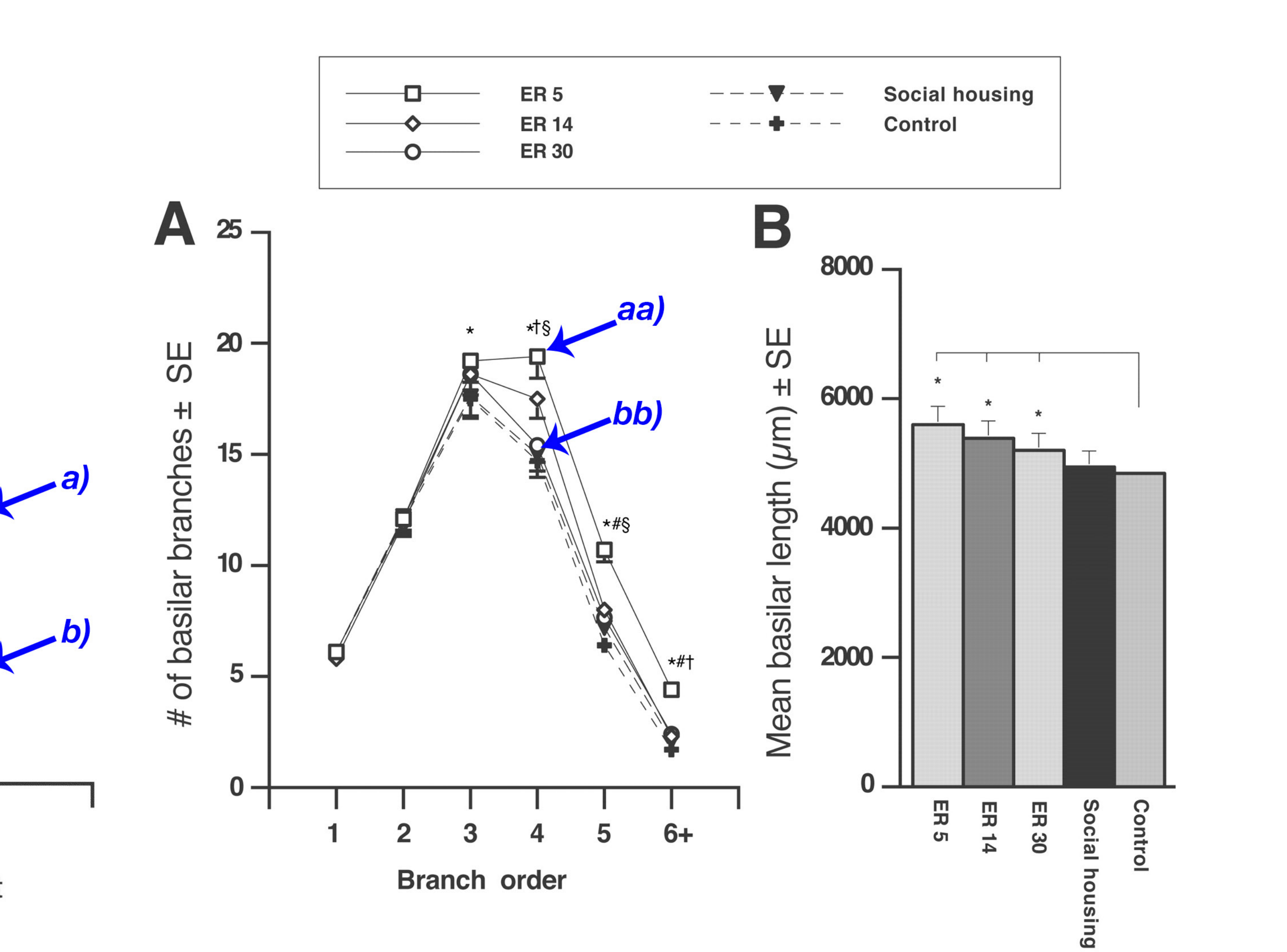
Right:
"Total dendritic length per cell in ER5, ER14, and ER30 animals was increased relative to controls; however, there was no change in length resulting from the ischemic insult" (ibid).

**ER5 - Enriched Rehabilitation, initiated 5 days post stroke (ER14 refers to initiation 14 days post stroke)*









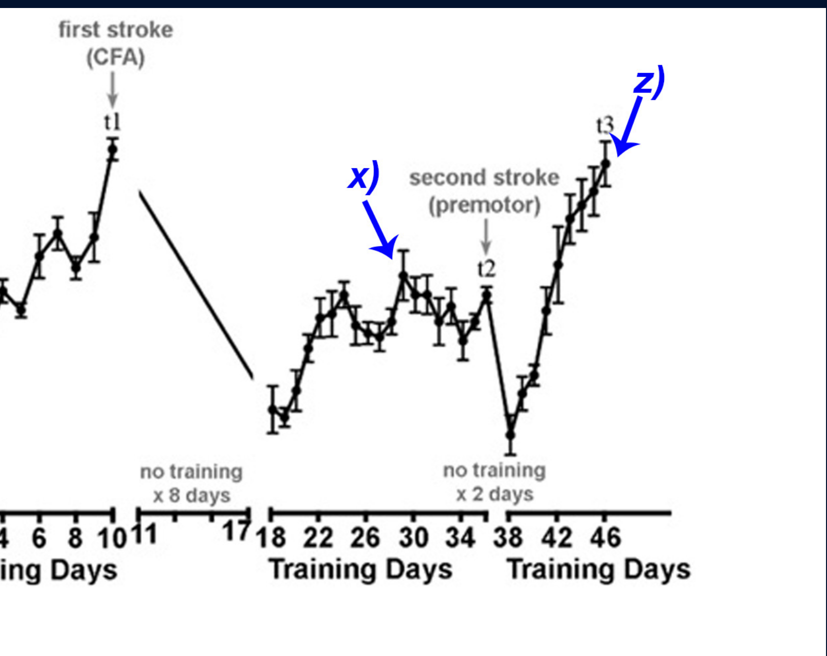


Figure. 1.4 Demonstration of a postischemic sensitive period
(Adapted from Zeiler et al., 2016)

Left:

"Schematic of experimental timeline. Initial CFA stroke at t1; Second stroke which occurred in either the medial premotor area (AGm) or in the visual cortex (occipital lobe) at t3; day of sacrifice at t3" (ibid).

Right:

"Mice were trained to perform the skilled prehension task [...] (t1) after which they underwent photocoagulation-induced stroke [...] After a 7 day post-stroke delay (t2), the mice were then retrained for 19 days. A second photocoagulation-induced stroke was then induced" (ibid).

1.3 Early Rehabilitation

25 mins spent on upper limb during sessions with OT/PT 3x per week (Stockley et al. 2019)

Patients 8% less likely to be re-admitted (Kumar et al. 2019)

£233 per day (RCP, 2016a)

Stroke Unit Rehabilitaion

Max length of stay: 71 days (RCP, 2016a)

↓ Information support & training

↓ Screening and assessment

↓ Setting goals

↓ Rehabiliation plan

Death in A.S.U

Specialist Rehabilitation

Post A.S.U Care

E.S.D (Early supported discharge)

Max length of stay: 63 days (RCP, 2016a)

Contact time:
OT mean visits: 9
£74 per visit
PT mean visits: 7
£52 per visit (RCP, 2016a)

24 mins spent on upper limb during sessions with OT/PT 3x per week (Stockley et al. 2019)

Drug therapies:
Reducing spasticity: baclofen and diazepam, act on the nervous system to reduce nerve signals to muscles;
Dantrolene acts as a muscle relaxant; treated focally with injections of botulinum neurotoxin.

22% only receiv

Physiotherap

Range of motion:
Supplementary Training Programs: e.g. GRASP Programme; Virtual reality; Robotics
As an alternative to some electrical stimulation methods, electromechanical and robot-assisted training assist passive and active movements (Mehrholz et al. 2015).
However, evidence on electromechanical and robot-assisted arm and hand training is of low quality (Mehrholz et al, 2015). [Indeed a recent 'RATULS' study was deemed misleading since the incorrect outcome measure was used].

Coordination
e.g. Finger Nose Test [test for dysmetria]; Rapid Alternating Movement Test [test for dysdiadochokinesis]; 9 Hole Peg Test ; Box and Block Test

Circuit training
Cardiovascular fitness training, particularly involving walking, can improve exercise ability and walking after stroke.
Mixed training improves walking ability and improves balance. Music therapy - Used for rhytham training but not for improving strength.
"The exercise bike was placed in the day room amongst people watching TV. There were visitors in there, so it wasn't an appropriate space to keep up with your training" (FF, 2019).

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Figure. 1.5 A diagram summarising data collected within the early rehabilitation period of the stroke pathway

Frequency of therapy during hospital stay (documented in 2010):

In UK:
Usually 2-3 weeks
(3 hours per day for
5/6 days per week)

In US:
Av. 2 hours per patient** for 5/6
days per week.
**some up to 4 hours (tended to be
those with longer hospital stay)

(Kumar et al. 2019)

Therapy

Cognitive functioning

Communication

Emotional functioning

Self-care

Swallowing

Vision

ved PT

Movement

1.7% only received OT

61.5% received both PT & OT
(Kumar et al. 2019)

py

Motor function

used with conventional therapy to improve
er limb function and range of motion. It is also
gested that FES may be used to improve sensory
rimination but only with long durations and high
uencies.
cimento et al. (2014) suggest that electrical
ulation may have the potential to improve
ngth after stroke by *"increasing activation of
or units and/or the cross-sectional area of a muscle,
n when patients are unable to undertake
rventions involving resistance exercises"* (ibid).
use of active stimulation in conjunction with
-oriented practice is suggested to improve
terity and reaction time (ibid). However, there is
ence to suggest that pairing tDCS with strength
ning does not produce significant improvements
rength.

Grip strength:
Hold and carry items - purse, bundle of clothes
vier weight as strength progresses)

Pinch strength:
Picking up coin, or larger objects to start with

Equipment:
Therapist, gym equipment/ exercise machines

Sensation

TENS, acupuncture, muscle stimulation,
eedback, monofilament Test (use different weights,
, and shapes of objects to promote discrimination).

ent injury by wearing gloves (prevent frostbite for
mple) or apply sunscreen (prevent sundamage)

Occupational Therapy

supported by:

Assistive technologies; hands-on techniques; Functional Dynamic Orthoses (e.g. SaeboFlex and SaeboReach); Constraint Induced Movement Therapy* (CIMT); Mental Imagery**; Mirror Box [http://www.mirrorboxtherapy.com]

** Outcomes related to CIMT generally relate to arm function. Where this method is seen as benefitical in acute stages (along with trunk constraints), the effects mostly confined to the trained activities (Pollock et al, 2014c, Pollock et al, 2014b, Veerbeek et al, 2014).*

*** Although mental practice is recommended and has a good evidence-base, it is not widely implemented into clinical practice (Stockley et al. 2019; RCP, 2016).*

Positioning Devices:

e.g. Joint Protection and Supports (slings or splints) [can encourage the rise of flexor synergies so are not useful in all cases]; Arm Boards (half lap tray or arm trough); GivMohr Sling; Omo Neurexa Sling (Otto Bock); Hemi Sling; Other (e.g.: pocket, belt, shoulder bag, waist pouch)

Retraining ADLs

e.g. Hold towel with hand; Wash face (2 hands); Brush teeth (2 hands); Dressing; Hold water bottle and pour it; Use remote control; Use knife and fork; Hold plate or bowl when eating; Apply wheelchair breaks; Hold paper down when writing

Other specific tasks regularly used in lifestyle:

e.g. Use computer mouse and keyboard, shaping hand on door handle when opening door (ULP: d). Or additional hobbies e.g. swimming.

"They should be trying to incorporate your arm with the motion of walking - swinging the arm - because you loose that and it's the small things that really highlight a difference" (FF, 2019).

Compression techniques

e.g. Oedema gloves and socks, pneumatic compression, massage, body suits. *"I had pneumatic compression to regulate blood flow and my circulation which was great"* (CE, 2019).

1.3.1 Overview

After rehabilitation has been established (Figure 1.5), there exists a number of challenges in supporting functional upper limb recovery post stroke, specifically, issues of maintaining levels of repeated exercise (Ward, 2005; Stockley et al., 2019), limited resources for doing so, and a focus on retraining quality movements for functional recovery (Krakauer and Carmichael, 2017). Where current RCP guidelines[10] (Intensity of therapy, section 2.11.1A) state; *"[undertaking] at least 45 minutes of each appropriate therapy every day, at a frequency that enables them to meet their rehabilitation goals, and for as long as they are willing and capable of participating and showing measurable benefit from treatment"* (RCP 2016b), current approaches are failing to meet this target by a reported 240% (Wade et al., 2017). With one-to-one clinician-led rehabilitation limited to six weeks post stroke, individuals are reporting feeling abandoned and unsure what to do (Ward et al., 2019).

1.3.2 Distinction between functional recovery and compensatory strategies

The approach to rehabilitation can also yield differing results. In general, there exists two distinct categories of upper limb stroke rehabilitation; firstly, functional recovery or 'retraining natural movement' and secondly, compensation or 'coping mechanisms'.

1.3.2.1 Functional recovery

"Functional recovery is associated with returning brain activation patterns back to 'normal'" (Ward, 2005). Following focal injury, functionally relevant adaptive changes are seen to take place in the brain (ibid). *"Although clearly brain activation patterns will not normalise in all patients"* (Ward, 2003a; 2003b). It has been observed that such changes are possible in the chronic stages post stroke (Ward, 2005) meaning retraining is possible even many years post stroke.

To regain functional recovery, it is fundamental to focus on the quality of movements performed (Krakauer, 2018; Krakauer and Cortes, 2018) which takes time. Using techniques centred around the Neurodevelopmental treatment (NDT), the 'Bobath Approach' (Figure 1.6), underpinned by the work of Bernstein (1967), is a conceptual framework which focuses on retraining quality movements. A focus is placed on 'how' a task is completed; emphasising continuous correspondence between the self, action and context (Shumway-Cook et al., 2016). This differs from 'Task Specific Training' [including compensatory techniques], where task completion is prioritised. It is believed that *"the use of structured task practice alone does not significantly improve motor function"* (Winstein et al., 2016). Rather than being a series of rehabilitation techniques and interventions (for

[10] The guidelines have their own limitations. Drummond (2020) suggests that, whilst a guide is useful to inform individuals, this can be misleading causing survivors and therapists as well, to use this as a 'tick box' exercise; i.e. stopping after reaching 45 minutes. Suggestions have been raised to review this since benefits of longer durations of therapy have been seen to show increased benefits to recovery:
Kumar et al. (2019) reported that patients who received 75 minutes more (than two hours total), were 14% less likely to be readmitted to hospital for support with physiotherapy in the future. "Findings also highlight that the current reported provision of upper limb therapy is markedly less than what is likely to be effective" (Stockley, 2019).

example FES, body weight support treadmill training or CIMT), complex movement challenges are addressed via an "individualised intervention plan" (Cott et al., 2011).

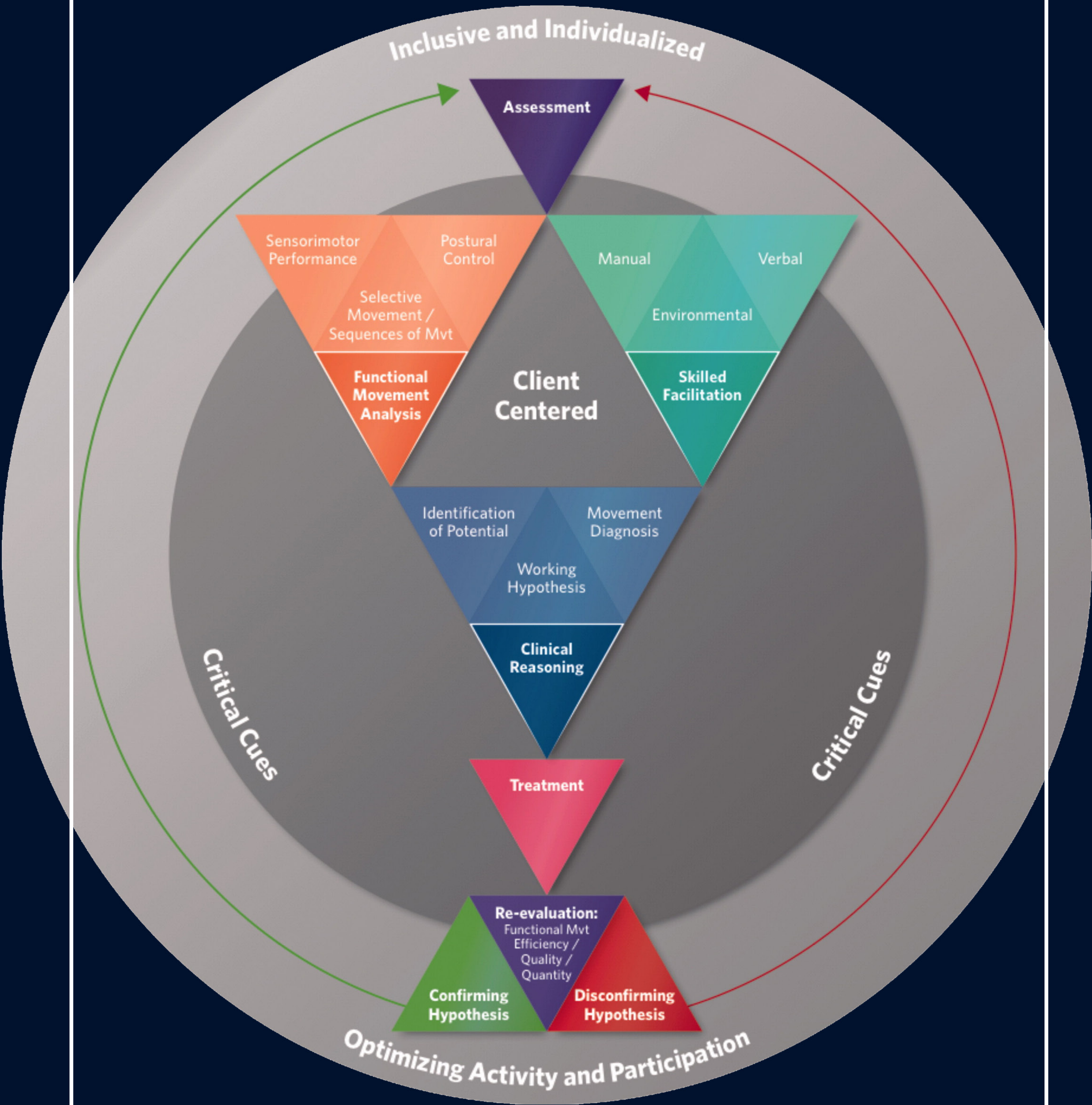


Figure. 1.6 The Bobath model of clinical practice. (Michielsen et al., 2017)

1.3.2.2 Compensatory techniques

In contrast, compensatory techniques often do not take into consideration 'how' the task is achieved; a cup may be picked up by not fully extending the arm, instead moving the trunk of the body closer, compensating for lack of limb extension. Emphasis is often placed on task success (ibid) within a repetitive task-oriented approach (French et al., 2016) for both therapeutic methods and clinical investigations (Winstein et al., 2014).

By using other muscles in the body to achieve the same task outcome, this results in reduced use of the affected muscles which may accrue further disability as a result of persistent non-use. The use of such compensatory techniques of 'coping' then becomes the automatic manner of doing things (Murata et al., 2008).

Murata et al. (2008) demonstrate that there often appears to be a dip in success rate when pursuing functional recovery, before the return of precision grip finally emerges (ibid). This can be misunderstood and off-putting for both the stroke survivor and, in some cases, the therapist, requiring time, dedication and understanding in order to push past this point. Whereas, with compensatory techniques there often exists a consistent incline of improvement, which can be misunderstood as signs of improvement, going on to limit long-term recovery.

Noticable gains offer hope to individuals to continue pursuing training: *"I remember laying in bed and I saw my fingers move. This was really motivational to me"* (FF, 2019). Particular methods of training can also help this: for example, the use of FES eliciting movement: *"showed it was possible that a connection could be made"* (ibid).

Clinicians suggest that, often, due to a lack of time available with patients (Stockley, 2020), a focus is placed on teaching individuals coping mechanisms, particularly in those most debilitated and who need the greatest support[11]. Attempts are made to restore function in stage four or higher, with consensus opinion stating that severely impaired upper limb treatment (less than stage four) should focus on compensatory strategies (Stockley et al., 2019). The ability to recover is still considered dependent on the extent of damage; 50% of those with severe hemiparesis are deemed the 'Non-Recoverers' since they do not meet proportional recovery 'standards' (Stockley, 2019).

Table 1.7 summarises data captured from hospital staff reporting approaches to rehabilitation across the UK according to differing levels of deficit[12]. A significant decrease is observed in additional unsupervised therapy from moderate to severe deficits with a greater emphasis placed on 'coping with the deficit' for severe cases. In contrast, milder deficits are seen to place a greater focus on task-based, structured exercise programmes in attempt to regain lost function. In some cases (~31%) additional therapy was given three times a week by rehabilitation assistants (Stockley et al., 2019). Whilst 29% reported that a carer or family and friends provided therapy every day for the survivor. The study also highlighted that the duration of upper limb training varied depending on where the patient was based; e.g. experiencing 21 minutes in the HASU/ ASU, 26 minutes in a 'general rehabilitation' department and 21 minutes with a therapist within the 'community', three times per week. All of which fall under the recommended 45 minute guideline per day.

Table 1.7: Approaches to rehabilitation: Data from a UK-wide survey (Adapted from Stockley et al., 2019)

	MILD DEFICITS *	MODERATE DEFICITS**	SEVERE DEFICITS***
% time spent on upper limb rehabilitation per treatment session	41	45	35
% patients who 'receive' additional unsupervised therapy	Unknown: "patients were given unsupervised activities to do"	95	79
Rehabilitation methods reportedly used and prescribed including the % clinicians who did so	1. 'Functional training/ practice' (59) 2. 'Exercise programmes' (38) 3. GRASP [*1] and PRACTICE [*2] structured upper limb programmes (32) 4. Table top activities (20) 5. Sensory re-education (11)	1. 'Exercise programmes' (46) 2. 'Practice of functional/ everyday tasks' (33) 3. 'Sensory re-education (24) 4. GRASP and PRACTICE structured upper limb programmes (22) 5. Mirror therapy (9) 6. 'Positioning' (9)	1. 'Exercise programmes' (43) 2. 'Sensory re-education/ massage (28) 3. 'Positioning' (26) 4. Advice and education (22) 5. Mirror therapy (8) 6. Splinting (8)

** "able to lift and hold arm up against gravity for 10 seconds"*
*** "some effort against gravity but the arm can't get to or maintain the proper position and drifts down before 10 seconds"*
**** "unable to move against gravity or no voluntary movement" (based on NIH stroke scale)*
However, this relies on subjective opinions to evaluate a spectrum of ability. More advanced methods of, for example, using kinematic measuring tools to provide more accurate diagnosis with reduced human bias.
*[*1] Graded Repetitive Arm Supplementary Programme - GRASP*
*[*2] Promoting Recovery of the Arm: Clinical Tools for Intensive Stroke Exercise - PRACTICE*

1.3.3 Barriers to rehabilitation

Variations in approaches to rehabilitation can be attributed to factors including: complexities in health conditions, pre-stroke health status, comorbidities and age-related factors often act as a barrier for participation in rehabilitation, especially in the early stages: *"The baseline for deeming individuals 'fit' for rehabilitation [in hospital] is so high, and perhaps over cautious"* (CO, 2019). Depending on the level of deficit, individuals may be unable to engage with some interventional tools (ULP:d, 2018). Additionally, not all methods of training are suited to particular behavioural needs: *"The OT gives you practical things to do like washing up. That made me angry and frustrated because it feels demeaning. I don't want to be given a washing up bowl and sponge. That's not even how I do washing anyway"* (FF, 2019).

[11] There exists less consistency in treatments reported for people with severe upper limb deficits (Stockley et al., 2019).
[12] Self-reporting presents issues of bias.

Intervention set-up times can present a barrier; if set-up becomes too long or difficult to set up, this reduces time that the physiotherapist has with the patient (Stockley, 2019). As such, the physiotherapist reverts to *“what they know best: hands on exercise and assessment”* (ibid).
Within current systems, the type of therapy delivered is beginning to change from a ‘hands on’ approach to providing advice in order to accommodate mental health needs (low mood and depression) which can pose a major barrier to recovery (Drummond, 2020). An observation by Ruth Parry over 15 years ago suggested that when ‘we’ chat (i.e. the therapist), ‘we’ tend to stop treating and offering ‘physical support’ (ibid). It may be considered useful to understand alternative methods for delivering mental health support, perhaps even from the perspective of stroke survivors who volunteer their time on the ward to support others.

Further issues pertain to a lack of focus on upper limb rehabilitation: *“a greater focus is often placed on the lower limbs during rehabilitation”* (Leff, 2018). It is suggested that this might be to avoid wheelchair use, a motivation to walk, along with a desire to leave hospital (ULP: d, 2018). However, *“there’s often a regret from patients that there isn’t a focus placed on the upper limb”* (ULP: d, 2018) since this is seen to influence quality of life, particularly, quality of independent living for which the upper limbs are required to perform key ADLs.
In the US there “is a general opinion that there is greater emphasis on the lower limbs due to the belief that you need both legs but you can ‘cope’ with one arm” (Krakauer, 2018). Consequently, where approximately two-thirds of survivors regain the ability to walk independently post stroke, less than half regain basic upper limb functions after a year (Broeks et al., 1999; Chen et al., 2015). Individuals suggest approaches could be rethought: *“They should be trying to incorporate the arm with the body. Walking with the arm, swinging it, because you lose that”* (FF, 2019). It is the small things that increase the difference between body behaviours and identities including such small gestures that naturally occur within everyday movements.

What is particularly apparent in the literature is that those who experienced milder strokes were likely to be younger, male, have fewer complications, receive thrombolysis and more intense therapy (McGlinchey et al., 2018). Individuals with fewer deficits and ‘barriers’, including pain, are also more likely to engage in rehabilitation. Efforts are required to consider how therapy might be delivered to those with significant barriers to both support the reduction of deficits experienced and further ones accrued as a result of non-use.

1.4 Post Discharge

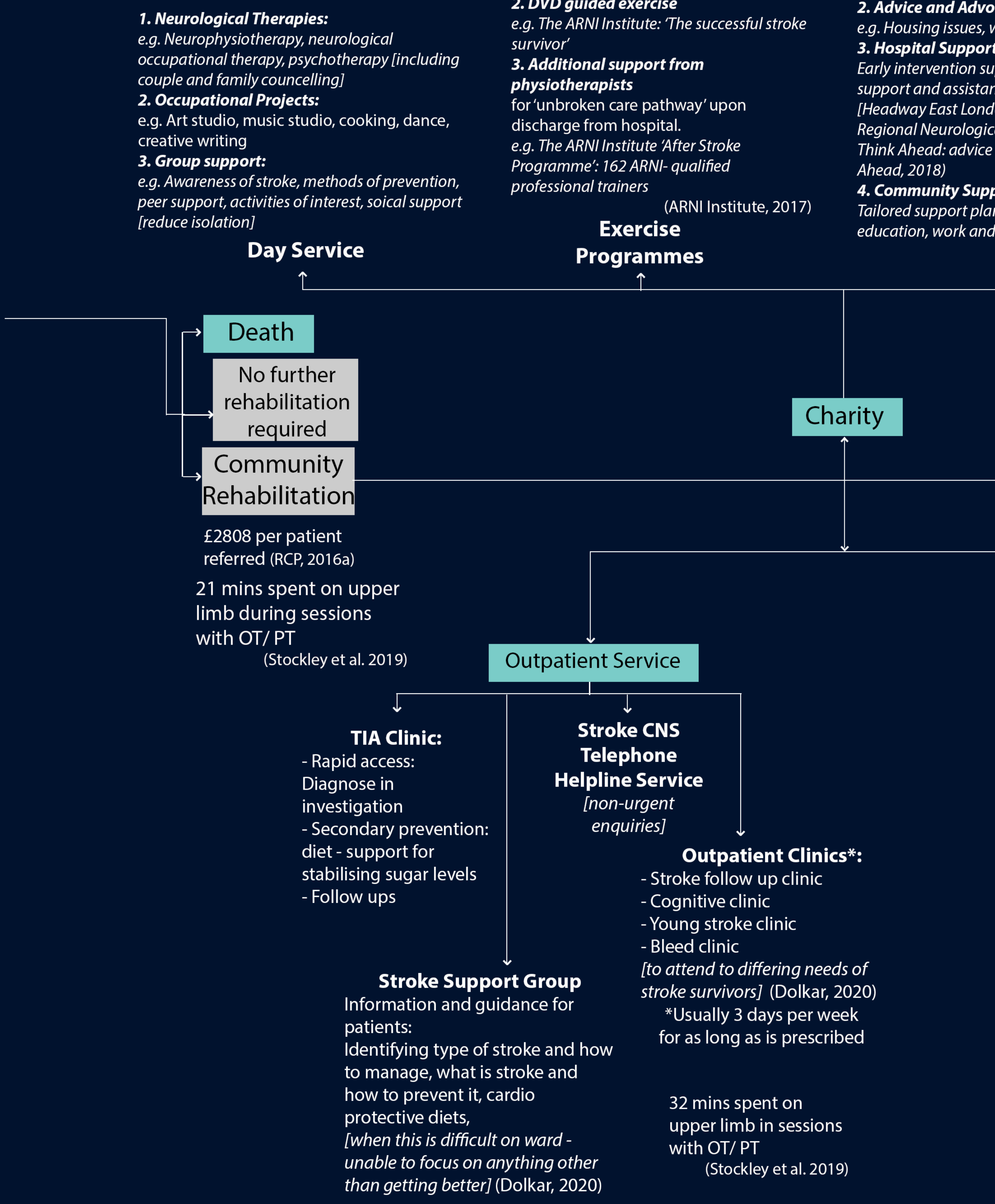


Figure. 1.8 A diagram summarising data collected within the post discharge period of the stroke pathway

mbers to gather, share experiences and provide peer support
1 in Hackney, x1 in Waltham Forest, x1 in Havering (Headway East

cacy:
welfare benefits, health and social care services, immigration
t:
pport to stroke survivors and their families: information, emotional
nce.
on offers this service in Royal London Hospital and Homerton's
al Rehabilitation Unit. (Headway East London, 2018)]
and information for stroke survivors, their carers and families (Think

port Work:
ns developed to empower people to engage in social activities,
I manage complex activities at home (Headway East London, 2018)

Case work

1. *Guided rehabilitation*
e.g. PhysiGo: Physigauge sensors to monitor and accurately measure movement; Neuroball: (Neurofenix); Saeboflex

2. *Passive support and aids*
e.g. FES implants (or external devices); oedema gloves (or sleeves); splints

Stroke recurrance rate: high risk in first month post stroke, especially following TIA or smaller strokes (Abid, 2018)

80% discharged home from inpatient rehabilitation (Dobkin, 2005)

Home

Care package: £37- 370 per week
10.3% - 50% (RCP, 2016a)
[depending on ability]

Care Home

£157 per day (RCP, 2016a)

Stroke Recurrence

Return to A&E

No further event

Death

Specialist Rehabilitation

NHS (Referral) - In-Patient

1. Regional Neurological Rehabilitation Unit (RNRU); Upper Limb Programme Queen Square [90 hours multidisciplinary upper limb rehabilitation over 3 weeks (Ward et al. 2019)].

Aims:
- detailed upper limb focus
- assessment
- discussion of goals, working to set plan for home
- referrals to other clinics where necessary [spasticity assessment clinic, upper limb FES clinic, orthoses clinic etc.]
- liase with local outpatient and community services
- referral to all patients over 16 years old

Hands -on, Tyromotion Robotics, in-house splints, FES, Sensory training [with familiar objects]

2. RLHIM Psychological Therapy Services [struggling to cope with illness causing emotional distress/ Chronic Fatigue Syndrome/ Chronic pain-related conditions]
Cognitive Behavioural Therapy, Hypnosis, Autogenic Training & Mindfulness approaches
[6-8 sessions based on need]
(University College London Hospitals. 2017a)

3. RLHIM Occupational Therapy ['find ways to do the activities or occupations that are meaningful to them but find it difficult']
Balance activity, manage limited energy levels, set achievable goals, learn activity analysis, relaxation skills, coping with setbacks.
Offer inidividuals a 'numer of follow up appointments' depending on need, lasting 40 minutes each
(University College London Hospitals. 2017b)

Private

BMI Healthcare
"Runs 69 private hospitals across England, Scotland and Wales o ering treatments including physiotherapy and speech and language therapy." (Stroke Association, 2020).

Priory Group
"Provides neuro-rehabilitation services at three residential centres located in Bury and East Sussex."

Royal Hospital for Neuro-disability
"A private hospital in Putney, London, o ering long-term care and rehabilitation treatment."

The Stroke Unit at the Hospital of St John & St Elizabeth
"A private hospital in St John's Wood, London, providing patient care and rehabilitation after the initial emergency treatment for stroke."

Physio First
"This is a CSP group for members in private practice."

Neural Pathways UK (Kings in Wade, 2017)

The College of Occupational Therapists Specialist Section – Independent Practice
"Provides an online directory of quali ed, private occupational therapists."

Leonard Cheshire Disability Acquired Brain Injury (ABI) Services
"Supports people with acquired brain injuries who are ready to leave hospital but still need specialist rehabilitation. "

1.4.1 Overview

Whilst the length of hospital stays fall, intensities of in-patient rehabilitation resources are failing to be replicated in the community resulting in patients receiving less rehabilitation (Rudd, 2017). Community support groups, specialist exercise programmes and clinics offer additional but varying support for individuals (Figure 1.8). In the case of community support groups, this can be in the form of social stimulus by getting individuals out of the house, sharing stories and providing peer support. Case workers can additionally help out with wider issues pertaining to disability support, appointments and referrals to specialists, as well as day to day requirements including housing. Specialist clinics such as the Upper Limb Programme at Queen Square provide intense rehabilitation training and support; introducing techniques as well as helping individuals to manage their own recovery plan.

Early supported discharge (ESD) is now provided In most areas services, supporting people to leave hospital earlier. However, there are often insufficient community stroke specialist services to support those with severe disability in their transfer from hospital to home.' (RCP, 2016b).

Delivering rehabilitation to 'adequate' levels beyond the hospital is limited. In the UK, it was reported that over half of stroke survivors consider available rehabilitation services as suboptimal (McKevitt, et al. 2010) and feel abandoned by the system post discharge: *"You get six weeks help then you're on your own after that." (RR, 2018); "Therapists leave it up to the family to help but they can't be with you all the time. It's difficult for families to know how to help"* (EE, 2018).

To place this into context, before it was known that the brain has neuroplastic ability to re-learn lost abilities following stroke, clinicians would wait until a six week period had passed before assessing the individual for remaining cognitive function (Taub et al., 2006). It was believed that, at this stage, the body would have recovered to approximately 90% of its 'new ability'. This was discovered to be incorrect (ibid). Yet still *"the general rule is that patients remain for 6 weeks in community care rehabilitation services post discharge. This is based purely on pragmatic studies, what the funding can afford, and not on any medical evidence"* (ULP: d, 2018)[13].

Kings (2017), suggests that it becomes a case of *"not what happens when we [PTs/ OTs] are there, but what happens when we are not there"*. Non-use impacts training programmes, which have to make up for declining movement and increasing stiffness that can happen over short periods of time: *"My arm feels tight on a regular basis. To the same amount each day, mainly at breakfast, but it does loosen throughout the day as I use it"* (HJ, 2018). Attending to this requires a change in lifestyle habits which can be difficult, affecting motivation and pursuit of recovery. Issues arise when approaches to on-going care do not fit into the lifestyle and behavioural needs of the individual. The need to persistently train can be unfamiliar to many who have not exercised to such levels of intensity pre-stroke. Furthermore, the time taken to participate in rehabilitation detracts from rebuilding one's life (DD, 2018).

However, *“[there exists an] importance of getting back to life and that in itself is rehabilitation”* (ULP: d, 2018), so transitioning from 1:1 support to independent methods of recovery and use of the limb is an important step.

1.4.2 Approaches to self-directed rehabilitation

Alternative methods may be considered to help boost gains and help to increase the intensity, frequency and duration of rehabilitation in the absence of a therapist: *“I’ve used Saeboflex™ at home for around 30 minutes per day which has helped with my hand extensions. The swelling of my arm has reduced since I’ve been using it more [and promoting better blood flow]”* (WW, 2018). However, similarly to therapist-led rehabilitation, set-up can also limit use: *“I have to move the electrode pads to adjust and get in the right place but once it’s on it’s ok”* (WW). Limitations depend on gains achieved: *“[Saeboflex™] takes a long time to put on but the effort is worth it”* (AA, 2018). In other cases, this can lead to device abandonment: *“I got a body suit to help with my ataxia but it’s so tight that I can’t even dress into it [with help]. Even the larger size. So it’s useless”* (HH, 2018); or alternative options where limitations are unavoidable[14].

With the exception of some devices that work with therapists (e.g Tyromotion™), to this day, robotics, VR and the use of support staff have not had significant enough uptake to replace core staff (Drummond, 2020). A therapist provides more than just upper limb training (Rodgers et al., 2019); including a level of social contact and communication, identifying other issues, taking a more holistic and intuitive approach to care that a non-human device may not. The value of ‘hands on’ therapy should not be underestimated. There exists a high dependency upon training with a specialist: *“There is no belief of any good being done for recovery outside of the clinic”* (UCL: d, 2018); resulting in a long waiting list for community physiotherapy (AB, 2018).

The design of intelligent interventions and services that take this into consideration is therefore an important part of securing improved health and wellbeing outcomes. However, the rise of disability studies has led to the re-questioning of approaches to ‘treat’ disabilities. It becomes important to question whether the research should pursue improving lived experiences and well-being via the treatment of post-stroke upper limb deficits or to design improved environmental living conditions.

[13] Therapy continues beyond six weeks for those who do not have any family (DD, 2018)
[14] E.g. implantable stimulation devices that may be used to avoid skin irritations pertaining from electrode pad adhesives (FG, 2018)

CHAPTER 2.0

Questioning need: Essence of ‘self’ and the creation of ‘other’ on the be-[ing] in care

2.1 Chapter 2.0 Overview

Although rehabilitation needs and early thoughts for intervening have been highlighted in Chapter one, the underlying reasons behind the pursuit of rehabilitation and, in some instances, pursuit of a ‘normal’, ‘familiar’ or an ‘ideal’ sense of self requires critique. The chapter therefore looks to justify the positioning of the research in looking to intervene, considering the consequences of doing so on one’s identity and ‘sense of self’ to which garments can hold influence over.

By combining constructivist epistemology with strategic essentialism (Spivak, 1993) this Chapter draws upon the development of assumptions used to shape society; *“invariant laws of nature, mere social hierarchies and normal over abnormal”* (Jeffreys, 2017), including aspects of disability law and eugenics, to question why we feel that, as society, we need to intervene. What leads us to view disability as something that requires ‘treating’ (see Degener, 2016) to regain a more “wholesome sense of self” (Jeffreys, 2017)? What causes us to view disability as less than?

An importance is placed on accounts collected through anthropological studies of individual experience mediated by the garment. Placing the voice of the participants directly within the text illustrates the conversation beyond where the author and scholars from the literature ‘speak for’ them (Spivak, 1988). The aim is not to provide extensive debates about what ‘being’, ‘care’ or ‘disability’ is, since these can be found elsewhere in the texts referenced, but rather provide an insight into the drivers which shape approaches to post-stroke care and behaviours that influence the methods, outcome and choice of recovery.

Perceptions of disability 2.2

The theories which have come to dominate thinking and shape the way we live throughout history have also contributed to the exclusion of certain groups of people. The construction of the term ‘normal’ is widely considered to be a pivotal moment that has come to re-shape the way we think about disability and pursuit of a sense of self that is ‘other’; within medicine, fashion and categories beyond these.

The term ‘normal’ entered the English language around 1840, meaning of *“constituting, conforming to, not deviating or different from, the common type or standard, regular, usual”* (Davis, 2006). It originated as a result of developments in statistics, a branch of knowledge created with the intention of collecting data about the state (Porter, 1986: 18, 24), to inform the development of the state, via increasing observation (Foucault, 1975).

Interpretations of the term have influenced the way individuals are treated socially, politically and economically; those defined by law (The Equality Act, 2010).
The term ‘average man’ was used prior to this in 1835 by Quetelet; again from statistics, the term combined moral and physical averages (Porter, 1986: 53) of human attributes which are seen to contribute towards this sense of ‘normalcy’. This was pivotal to the contributions of a socially constructed ‘norm’ of self and of groups of people *‘les classes moyens’* (or middle class); a class most celebrated for ‘moderation and middleness’ (Porter, 1986: 101). This class held desirable traits including the association of good health (Defoe, 1975); not overeating like the upper class, neither malnourished like the lower class. Health, in particular good health, became a depiction of a ‘norm’ and a desirable way of life: *“health is wealth and a sound mind in a sound body is the most priceless of human possessions”* (Kevles, 1985: 62).

Today, where high sugar levels and processed foods are more readily available to the lower classes at a lower cost than healthier alternatives in most cases, higher levels of depravity and complex psychological webs related to advertising and the food industry are associated to the accumulation of diseases such as diabetes and stroke (Wisman and Capehart, 2010; Baker, 2020). As groups migrate and it becomes easier to experience foods from other parts of the world which was not possible 50 years ago, as such, changes in diet has impacted health (Popkin et al., 2001; Baker, 2020). When paired with limited growth within the health and educational sectors reducing lack of awareness, incidences of severe stroke are rising within more deprived areas of society (RCP, 2016a). This is not necessarily out of choice of the individuals but due to bad planning of the structure of living (low economic growth, limited income and green spaces, paired with high availability of low-cost fast-food shops, for example). Furthermore, reduced access to higher levels of care (e.g. being able to pay and benefit from private physiotherapy, or tools to help recovery) places a reliance on free accessible services within the community and NHS, where often, demand outstrips supply (Stockley, 2019).

Historically, the disabled ‘body’ (defined by bodily attributes) became grouped with people who were considered ‘unfit’ and ‘undesirable’; with criminals, those of mental incompetence, low intelligence and the poor. This was the ‘defective class’ (a pre-WWI attitude) under the theory of eugenics (Davis, 2006). The inflection of representations of socially constructed disability identities in line with such ‘unhealthy’ and ‘other’ characteristics throughout literature, have also played a key part in this; documenting ideological shifts in representations of the self and others (Korotkova, 2017). Examples appear in distinctive texts such as Shakespeare’s Richard III, Homer’s Polyphemus and Victor Hugo’s Quasimodo (ibid, 2017) to name but a few.

These binary notions of thinking of difference as a result of ‘power’ lead to *“dualistic oppositions such as science vs. subjectivity, masculine vs. feminine”* as well as the abled vs. disabled (Minh-ha, 1988). *“Many of us still hold on to the concept of difference not as a tool of creativity to question multiple forms of repression and dominance, but as a tool of segregation, to exert power on the basis of racial and sexual essences”* [including those also related to disability] (ibid).

Within medicine, the term ‘normal’ has been used extensively as a method of efficiently describing and distinguishing between matters originating from the self in ‘ordinary circumstances’ and matters which are ‘abnormal’; posing a threat to the finite balance of systems that sustain life (Foucault, 1973). However, this sense of being 'other', less than 'the average man', even less than 'fully human and therefore, are not fully eligible for the opportunities which are available to other people as a matter of right' (Dart, 2002) still exists: *"Some people look at me and say that I'm disabled and so I can't do anything. They think I'm useless"* (TT, 2018).

Patterns of disability can be seen within Industrialist societies, who have created new forms of disability via the accumulation of *"workplace impairments, chronic lung disease, repetitive stress disorders"* (Davidson, 2006) and more; all of which dominate the lower classes. In response to this and consequential unemployment rates, health and rehabilitation services have become developed, re-shaped and *"exported to developing countries"* (Holden and Beresford, 2002), where more than 80% of the world's population of persons with a disability live (Davis, 1995: 8; Charlton, 2000: 7; World report on disability, 2011). In these cases, the impairment is seen as needing to be 'fixed' or 'treated'.

However, changes in the way disability is thought of, has led academics to consider the opposite; where society is a limiting factor denying the individual inclusion, not the disability. It is society which fails to accommodate groups of individuals (Pullin, 2017) that requires changing, not the individual and their impairment (Shakespeare, 2000; Johnston, 2003). Current readers in disability focus heavily on social models rather than medical models (Garland-Thomson, 1997). The social model originates from the 1970s 'Union of the Physically Impaired Against Segregation' (UPIAS) who outlined the 'Fundamental Principles of Disability' (Oliver, 1996), defining differences between impairment[1] and disability[1]. It has influenced the perception of disability (Traustadottir, 2009).

Notably, this binary notion of high income economies (HIE) leading the way with framing the social model is changing. Models of inclusive design aree seen to facilitate this, becoming adopted in LMIC and acknowledging that such populations should hold control in determining their own future (Zililo Phiri et al., 2016). Yet there still exists a disparity between social models of those more integrated, or involved with disability, and the rest of society: *"in our present collective cultural consciousness, the disabled body is imagined not as the universal consequence of living an embodied life but rather as an alien condition"* (Korotkova, 2017). Corrective methods, as far back as the 1850s, were seen in medicine as progress (Flaubert, 1965: 125). When considering the future of stroke rehabilitation, it becomes important to understand what it means for the individual to either pursue 'normal' movement patterns versus 'accepting' the way in which their body has transformed (WX, 2019). To understand this further the term 'care' will be unpacked to analyse approaches to post-stroke care and pursuit of 'recovery'.

Notions of 'care' and 'recovery': between, with and about others 2.3

The phenomenon of care[1] is defined by Heidegger as a being in the world with concerns; or cautious dealings with the ready to hand, be that others or things (Heidegger, 1926). Heidegger defines this 'concern' as a 'character of being' and of being Dasein[2] as one of

[1] 'Care' may be specified based on context; e.g., 'healthcare', 'social care', 'home care' or 'self-care', all of which can, broadly speaking, include varying levels of 'treatment', 'prevention' and 'cure' as demonstrated in Chapter one.

[2] See Glossary

‘solicitude’ (ibid: 157), to care or hold concern for someone or something epitomises an element of what it means to be human. The notion ‘to care’ exists as a result of either ‘being with’ and/or ‘being without’ someone or something[3].

It can be transactional to replace a shortcoming of another, given by a ‘care provider’ to the ‘recipient of care’, stepping in and replacing self-care (ibid). Depending on circumstance and attitudes towards care, this may be deemed ‘necessary’, ‘required’ or even ‘requested’[4]; as well as both paid and unpaid, which can impact the type, quality, duration and access to care (Rodgers et al., 2014).

The care system can provide a level of ‘human’ contact and support that changes lives. However, the approach to care can impact the recipient’s sense of self-worth[5]:

> “The biggest thing that hurts is when people decide everything for you. I already felt useless but now even my personal choice was taken away. I felt even worse”
>
> (DD, 2018).

When choice is removed individuals report feelings of anger: *“You aren’t yourself in hospital. You can’t say yes or no. They help you to dress. When your brain comes back then you can say yes or no. It’s a big thing that hurts you when people decide everything for you. Feelings of anger build up inside”* (DD, 2019).

This can have a direct impact on the public-facing self (explored further in Chapter three) but also impacts relationships: *“My ex-husband used to have to dress me. It was embarrassing and I felt ashamed that I had to have someone do that for me. It changed our relationship so much that, well, we aren’t together anymore”* (KK, 2018). When the carer is a friend or family member, caring can come at a *“great cost [...] many [of whom] are forced to give up work to care [whilst also becoming faced with] considerable additional costs”* (Rodgers et al., 2014). This can include a carer’s neglect for their own self-care.

Disability undoubtedly impacts relationships following brain injury. The effect on both the spouse, relative or friend, and the stroke survivor remains underexplored (Kreutzer et al., 2007; Arango et al., 2008). In some instances, individuals use compensatory strategies to avoid depending on another: *“I prefer to dress myself. So I do everything with my left side (unaffected) and I cope”* (BC, 2018).

[3] “Being for, against, or without one another, passing one another by, not “mattering” to one another - these are possible ways of solicitude” (Heidegger, 1926: 158).
[4] “Leaps in and dominates” (ibid: 159).
[5] Just as “solicitude is guided by considerateness and forbearance” (ibid: 159), the level of consideration, or empathy (Mercer and Reynolds, 2002), for the other in the act of care can vary greatly, even reaching extremes of “inconsiderateness” (ibid), impacting the experience of care.

Where care may be defined as a *"provision of what is necessary for the health, welfare, maintenance, or protection of someone or something"* (Rodgers et al., 2017: 1) care can also be damaging, degrading, and become heavily influenced by the underlying ideologies that have come to portray disability and need, in manners which have been discussed. Care can be enforced, literally, or lead individuals to think they need care and therefore demand it. Without it, individuals can feel useless, underserved, frustrated and 'not cared for'. As a result, care, including self-care can be 'more problem than cure' (Rodgers et al., 2017: 1) causing further problems and dominating life: *"I do have a life outside of rehabilitation you know, life does exist outside of rehabilitation"* (WW, 2018).
In contrast, there exists a type of solitude which does not leap in for the other as a 'provision', replacing him/her, but leaps ahead of him/her (Heidegger, 1926: 158). In this way care is seen to empower the other to give it back to him/her, not detracting from life, but rather supplementing it, enhancing and enriching it; even to, in some cases, simply 'let be'.

'Empowerment' in this respect can be considered on different levels:

i) By training the individual to care for themself [6]

ii) By stepping back to allow space for self-care[7] to take place

iii) or in reconsidering the means by which to be 'independent'. Contrary to 'doing things for yourself' (French and Swain, 2013), it is rather a method of being in control of, having choice and removing/reducing the barriers which self-care can present:
"…independence is not necessarily about what you can do for yourself, but rather about what others can do for you, in ways that you want it done" (Ryan and Holman, 1998: 19).
Empowerment takes the form of reinforcing a presence, a purpose and identity of being; placing the needs of the individual at the heart of training, within a holistic manner to consider not only the task at hand but the factors surrounding this[8].

iv) Or alternatively, by re-focusing on the construction of society and its re-shaping rather than the disability itself to enable a quality of life to be lived within a more 'inclusive' society.

2.4 Reflections on post stroke disability and approaches to 'care'

As has been established in Section 2.3, the pursuit of recovery and care can be isolating, excluding and degrading. Anthropological study shows that attitudes and behaviours towards post-stroke care vary depending on the individual. These are depicted in three overarching categories; 'total dependency'; 'rejection of care'; and 'rethinking recovery' (Table 2.1), occurring at different points in time, in any order, amount and extent.

[6] If knowledge required to care is not already known by the individual.
[7] Either be caring for oneself (self-dependence), or having a correspondence with a tool or equipment that enables self-care (requiring a level of correspondence; not necessarily 'passive' in linearity of care, which would refer to care being administered and taking over the role of the self).
[8] Including the implications of pursuing both movement (in line with functional recovery - factors rising from not doing so - i.e. further declines in health), and the emotional implications of recovery (emerging within stroke rehabilitation strategies but limited by the amount of time available - taking over training time and so often a priority is considered as to which one to focus on).

Table 2.1: A summary of participant behaviours towards post stroke recovery

	Pa	
	Total Dependency	**I**
Summary	Conforms to prescribed methods by the care-provider.	Rejects and beco acknowledge they
Impact	i) Requires resources for maintaining consistency in care. ii) A disparity occurs when discharged, and care becomes limited and/ or self-administered iii) Individuals can report feeling completely abandoned (Ward, 2017) and scared to re-enter the community and home environments: where there is an absence of 'professional care providers'. iv) High levels of reassurance required so that the individual knows what will happen and to be prepared to work towards or not.	Results in non-complia 'treatment'. This can be i) fatigue or medication 'intensive tasks' (ULP: p ii) social factors includin options or 'quick fixes' when the outcome of re An individual may wish possible in order to aid remove themselves fron Or, they may be fearful since returning to the h experiences in a new m they did before (WW, 20
Key Insights	1. "It's difficult for families to know how to help, so you feel like you have double issues: the stroke and people who you rely on [after discharge] don't know how to support you" (EE, 2018). 2. AA (2018) suggests that PTs in the past have used the strategy of telling him he can't do something to play to the fact that he will do all he can to prove them wrong by working harder. However, in others, a prognosis can have damaging impacts on others: "Another guy who had a similar disability [to me] was told he wouldn't get better so he just gave up" (FF, 2019)	Non-compliance can ex 1. Embarrassment in en attached to a particular summer when I'm wear because you can see th 2018). 2. In some cases indivic have had a stroke (Crow never free of it" (FF, 201 3. Frustration in not bei 'basic' task, either due al., 2018) or ability. 4. Fear of injury impacti to work but I'm worried and falling" (BC, 2018). the family from men in p stress post-stroke and meant to be the one wh 2018). "Doing things tha really important" (XY, 20 mental health with seve acknowledging a conte job, my pride, my relatio wants to associate with get too much. At one p 2018).

rticipant Behaviour	
Rejection of Care	**Rethinking Recovery**
omes dismissive of any care, failing to 've had a stroke, instead focusing on something else.	Pursues methods adapted to suit their own needs. The individual acknowledges the stroke but rejects prescriptive methods.
nce and lack of engagement in e due to further complexities including: preventing them from undertaking oo, 2018) ng reduced self-worth, looking for easier to regain the 'old self' or deflated feeling ecovery does not live up to expectations. to return back to the home as soon as the blocking out of the experience and m environments associated with 'care'. of this process and want to be elsewhere, ome means facing up to lived anner, and of not being able to live how 018).	Individuals may choose and adapt methods of rehabilitation to make them more useful for their needs. This can have contrasting results, potentially enhancing recovery, or stifling it either due to injury or enhancing compensation.
xist for a variety of reasons, such as: ngaging with rehabilitation due to stigma task e.g. "I won't use the FES in the ring shorts [for a lower limb deficit], e wires and people just stare" (WW, duals choose not to disclose that they we et al., 2018); "once people know you're 9). ng able to achieve what is seen as a to additional cognitive deficits[9] (Crowe et ing behaviour: "I'm desperate to get back about using the tools, climbing the ladder Social pressures of needing to provide for particular, demonstrate the complexity of reveal social stigmas: "It's what I do. I'm o provides and right now I can't" (BC, at give you a sense of accomplishment is 017). This can have a profound effect on eral individuals within the research openly mplation of suicide: "I lost everything, my onships broke down. After stroke no-one you. The stress and financial strain can oint I considered taking my own life" (VW,	"Physios are very good at giving exercises but patients are very bad at doing them" (ULP: d, 2018). Reasons for this include: 1. The type of care or approach to care may not be suited to their personality or lifestyle: "I was frustrated in hospital because the nurses were constantly telling me to be careful. But all I wanted to do was to push myself to get better" (WW, 2018). 2. Lack of choice which is considered to be one of the most important elements that make a difference to recovery: "Being able to explore options and make my own decision was the most positive difference to my recovery" (KL, 2018). 3. Yet, excessive training to achieve gains and recover can lead to further injury or extreme levels of fatigue: "The problem is I don't think I've done enough so I push myself until I get that I end up feeling extremely fatigued" (FG, 2018).

[9] A familiarity in methods can be useful (Crowe et al., 2018).

2.5 Chapter 2.0 Summary

The way we have come to view disability can affect approaches to treatment and recovery. The language used, 'otherness' and 'misfit' or a lesser self, influences the pursuit of a more 'normal' and 'whole' self. The language used 'obscures' (Heidegger, 1947: 14) and deforms' (ibid: 12) *"what it is to come of be[-ing]"* (ibid: 14), attaching misunderstood, misaligned meaning that can reduce the self to its bodily component parts.

Treatment of what is seen to be a deficit can be a devastating realisation of the lack of consideration for the 'self' as a whole. A focus solely on the 'pathogenic principles' of the 'impairment' results in wider consequences that exclude, impacting a quality of life where cultural rules control who the individual behind the disability is and what their life should be like (Garland-Thomson, 1997: 6). Research conducted by Dr Lindsey Oberman on the documentary 'Can you rebuild my brain?' (2018), focuses on 'unlock[ing] empathy' (ibid) in a gentleman with Autism via TMS (Transcranial magnetic stimulation). As a result of treatment 'success', the gentleman explains how he hates his new self; describing Autism as being his 'comfort blanket protecting him from the world'. This 'difference' or 'alterity' arising from thoughts created from 'homogeneous societies' (Ingold, 2018) was not an issue that needed solving, but a benefit; a diversity that should have been celebrated. 'Otherness' defined by Ingold (2018) as being a constant differentiation between selves is further suggested by Gilbert Simondon and Gil de Leuress as an ever emergent form within the matrix of relations within which we are immersed (ibid). Changing this changes the self.

Individuals should be able to live with a deficit/a defining feature of the self, since non-use or absence of a limb can be present from birth or as a result of a life event (broken arm or infection leading to amputation). When evaluating wider ongoing consequences of non-use of the upper limb, persistent non-use associated with some compensatory techniques causes further deterioration of health, in manners which can be painful and life threatening, (e.g. stiffness, swelling, pain, reduced circulation, muscle shortening, shoulder subluxation and increased limb weight which can make movement more difficult): *"Distortion can occur if you don't use your arm. It also becomes more difficult to use"* (XY, 2017),

It becomes important to discern when and how to intervene. Although the social model is important within care to provide a contextual understanding of an individual (Bose, 2017) an understanding of the impairment via the medical model is imperative if the underlying mechanisms that contribute towards further decline are to be attended to. Therefore, addressing both the social and medical, or rather, biological models, i.e. the bio-social model, accepting that there is a biological need (requiring 'medical' intervention) but which still works with and within the social model (Thomas and Milligan, 2018).

The pursuit of recovery is greatly reliant on the individual behaviour expressed post-stroke. Prevailing social stigmas that have come to define disability are evident within participant responses and influence the manner in which the self is viewed post-stroke, but also the way recovery is pursued.

Key challenges emerge from this chapter concerning the use of garments as therapeutic interventions.
Firstly, it becomes particularly important to consider how the presence of the intervention in the garment changes the way the garment may be perceived. Questions that need to be explored further towards understanding how the garment is viewed by survivors post-stroke first, and how has this perception changed, if at all? Investigations may then focus on other types of existing 'wearable aids' and 'devices' that are currently used in stroke to better understand users' experiences towards them.

Secondly, the level to which the intervention may highlight or conceal the disability requires thought when moving forward with developments. The research should not only consider what is preffered by users, but also the wider consequences of pursuing that choice on wider conversations around disability. Although it is out of scope to explore this depth, it is an important point that should not be neglected for the influence of developments can have, as we have seen in this chapter, significant impacts on the way people live their lives, both those who are considered 'disabled' and those not.

To investigate these points further, Chapter three will embark on using the garment as a research tool to explore post-stroke identity, perceptions and behaviours of existing wearable interventions and aids.

CHAPTER 3.0

Positioning the garment as a [research tool and] platform for care.

3.1 Positioning the thinking

"Dress is a basic fact of social life" (Entwistle, 2000: 323). It is a behaviour that can provide significant amounts of information about the wearer, the context the wearer exists in, and their correspondences to and with others. Garments are positioned as *"records of lived, [expected and imagined] experience"* (Sampson, 2018: 342). Within this part of the research they are presented as a research tool, a design probe for evaluating the post-stroke self; not solely in regards to the identity or character of self, providing critical information about the wearer's behaviour within wider concepts of lifestyles that can influence approaches to recovery, but also in regards to ability and perception of ability from wider social constructs.

The chapter will begin by defining the garment, its qualities and associations with the self, before presenting key findings from a long-term anthropological study with stakeholders investigating post-stroke identity, perceptions and behaviours of existing wearable interventions and aids. The chapter will conclude by re-positioning the garment as a promising tool for recovery and 'platform for care'.

3.2 Case study: The garment as a research tool

3.2.1 Defining the garment

For centuries garments have been imbued with social meaning and functional attributes, in multiple entangled manners; beyond adornment where the body is seen as a 'passive surface inscribed by various forms', as social signifiers (Bourdieu, 1984; Wilson, 1985; Skeggs, 1997; Crane, 2000), organisational methods for the development of modern society (Simmel [1900], 1989). In addition to associations for 'social performances' influencing behaviour (Goffman, 1959; Finkelstein, 1991, 1996, 1998, 2007; Bovone and Mora, 1997), the garment also extends bodily functions and attributes (e.g. acting as an additional layer to trap and regulate body temperature), further still holding the capacity to 'attach' or 'equip' the self with further functions; e.g., the ability to monitor body vitals and connect to external 'appliances' (Van Langenhove et al., 2007). In recent years, the rise of 'smart' textile technology (first defined in Japan in 1989) has seen the garment hold greater possibilities ('passively' sensing, 'actively' reacting and/or adapting as a result [Zhang and Tao, 2001]), albeit not yet within mainstream fashion.

The term ‘garment’, derived from the Old French word garnement meaning ‘equipment’ or from garnir meaning to ‘equip’ (Oxford English Dictionary, 2019). Where Heidegger makes reference to the garment as ‘equipment’, he suggests that the garment is a ‘sign’ or ‘symbol’ by which we come to recognise and associate meaning towards and of others (Heidegger, 1926: 79; 107); i.e. depending on further interconnected factors such as context, the garment is representative of human and non-human meaning. In the literature, the ‘body’ is seen to gain meaning via cultural influences (Mauss, 1973; Foucault, 1977, 1986), but in doing so, reduce ‘the self’ to ‘puppet-like actors’ (Entwistle, 2000). In contrast, Merleau- Ponty (1976, 1981) suggests that the body becomes a part of, and is seen to ‘embody’ society from a phenomenological perspective. In terms of contextualisation and appropriation, it is evident that those who are not subversive and instead adhere to the ‘social codes’[1] (Entwistle, 2000), reduce the risk of ridicule, stigma and exclusion. For social codes have determined, through the construction of the ‘norm’ (Chapter two), which body image and ‘sense of self’ is appropriate in which context, and which are excluded. In cases where this is not possible (i.e. due to health-related reasons) stigma may be unavoidable.

3.2.2 Positioning the garment as a design probe

The use of garments as research tools is not new. Ranges of studies have used the garment as a research tool previously, e.g. Sampson’s PhD thesis (2016), Ivanova’s PhD thesis (2015), Earley’s ‘Shirt Stories’ (2019), Storey’s Catalytic Clothing (Storey and Ryan, 2011), Skinship (Solomon, 2020) and Ballie’s PhD thesis (2014) to name a few.
Throughout this case study alone, the garment demonstrated several applications as a research tool/ probe[2] (Figure 3.1):

1) Exploring the sense of self/ personal identity pre- and post-stroke

Garments that were once worn, but not any longer as a result of stroke/ brain injury, explore the self that is either pursued in recovery, grieved for, abandoned or reimagined. The garment recalls key life events leading to discussions about preferred sense of self and future identity.
Associations are often, if not always, primarily associated with the wearer. Then to ‘others’ who have worn a similar garment, with whom the garment was worn in the presence of or the individual who may have gifted the garment (Strathern, 1988; Gatt and Ingold, 2013); retaining memories through reflections, stains, smells and wears and tears it contains as a result (Sorkin, 2000). Within the space of wearable medical ‘devices’ there may also exist an association with the care provider and/ or bodily ‘disease’/‘injury’.

2) Understanding post stroke ability: demonstrated through the dialogue and contact between the self and garment during dress

A platform for discussing day-to-day scenarios and functional aspects of the act of dressing. Focusing on garments worn by participants during the sessions provided opportunities to demonstrate and share experiences/ challenges about dressing/wearing a garment in person (Figure 3.2);

[1] Or semiotics, i.e. visual or behavioural symbols of representation as it is understood within a culture/ sub-culture.
[2] All sessions were voice recorded with consent gained prior to the start of the session.
Consent forms were used to formally record consent; updating these after every six sessions.

3) As an 'adaptive' probe that can be cut up, remade and amended; providing the opportunity for participants to consider alternative futures

By making, constructing and sampling garments through participatory methods, participants were given the opportunity to take greater control of determining possibilities of the garment construction, textile composition and visual identity. With the aid of the researcher participants were able to direct changes to be made to a garment to suit their personal needs and preference, or to partake in the making of an entirely new garment to suit (Figure 3.1). The toiles produced during these sessions were subsequently tried on, cut up, manipulated and/or remade demonstrating the qualities of the garment that are preferred which would later inform the development of a garment specification (Chapters seven and nine).

Figure. 3.1 Photo compilation: The garmen
design tool (Headway, 2018;

t as a design probe and participatory
2019; Author's archive)

Figure. 3.2 Knowledge exchange through the act of wearing: fit sessions and dressing demonstrations (Headway, 2018; 2019; Author's archive).

3.2.3 Case Study Findings

Responses were categorised by thematic analysis (Braun and Clarke, 2006) and revisited in a re-cap at the beginning of the next group session. This enabled participants to reflect on and discuss each other's responses, whilst ensuring interpretation of findings were true and not misconstrued or taken out of context; reducing researcher bias.

Findings from the case study were categorised into the following themes:

1. Personal image pre and post stroke: 'Recreating oneself'

2. Changes in the way the self is treated by both friends/family and the general public: 'Garment: body behaviour[3] during wear'

3. Dressing abilities; 'Garment: body behaviour in dressing'

4. Garments as medical devices and issues with rehabilitation/ post-stroke care;

[3] The manner in which garment: body dialogue has been discussed in fashion theory has varied (Appendix 1.1). This research takes a relationalism standpoint, which is seen to influence the nature of thought behind material interactions with post-stroke recovery (Chapters five to nine) in the construction of bead concepts 1.0 to 3.0 later on in the thesis.

3.2.3.1 Key insights

Theme 1 - ‘Recreating oneself’

Discussions explored expressions of ‘lost identity’, reflections on who one used to be, frustrations regaining their ‘pre-stroke self’ and ‘sacrifices’ made in order to live comfortably:

> “As you grow up through life you form an identity through your clothing, [...] through everything you do and it becomes part of your personality.
> When you first become disabled you’re very bound by clothes that fit comfortably, that fit over splints, that you can actually get over your arm. So you lose a bit of your identity through your clothing but you lose a bit of your identity
> because your body has changed and your perception of self is something ‘other’ than what you are used to”
> (WX, 2019).

Garments stand as a reminder of previous ability; through changes of body behaviour, some garments can no longer be worn:

> “I felt really uncomfortable [going outside]
> because I can’t wear that top,
> put my earrings in,
> can’t put my makeup on”
> (HH, 2019).

Although fashion has, in recent years, attempted to break many of the barriers which limit the acceptance of garments worn in particular contexts and by particular people, in particular ways, e.g., swimwear brand Chromat (Vogue, 2020) challenging Victoria’s Secret’s perception of ‘ideal’, the socially constructed contextualisation of garments still dominates thinking:

“A [stroke survivor] who I had known for a long time came in and said:
‘I am so sick of having to wear shell suit trousers all the time’
And I’d never really thought about the ramifications of [...] what that might mean to one’s sense of self [...],
that having to wear certain clothing because you only had use of one hand to pull it on meant that you were limited in what you could say about the world, how you wanted people to view you. And it suddenly dawned on me that this was a really significant problem”

(SW, 2019).

Changes in behaviour and movements are seen to impact the way garments behave on the body; fitting differently and limiting what can be worn: *“The numbness [and lack of movement] in my right side meant that my strap or sleeve falls off my shoulder. It doesn’t hold onto the body as well and I have to keep adjusting it”* (JJ, 2019). *“What you have to realise is that the body doesn’t move or sit in the same way anymore and so your clothes don’t hang on your body like they should”* (HH, 2018).

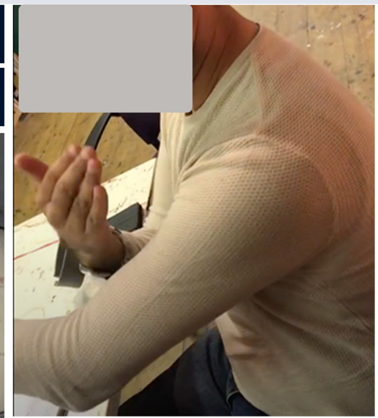
Post-stroke, the level of ability and degree of ‘choice’ one has to control correspondences to a certain, expected degree can be limited. Social constructs which lay parameters for what garments should be worn in which context and why, do not account for the limitations of accessing garments with ‘disabilities’. For example, of not being able to wear heels due to issues with balance and fears of falling over (HH, 2018), or the inability to move one’s body through the spaces within the garment due to movement deficits.

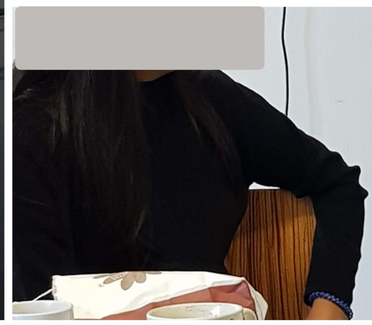
Table 3.3: Theme 2 - 'Garment: body behaviour during wear'

	Factors impacting garment experience during wear		
	Weight of the garment	**Textile thickness**	**Stretch and fit**
Summary	The weight of the textile combined with the surface quality can act as a barrier to wearing garments. Too light and "slippery" (HH, 2019) and it does not maintain good contact with the body. Too heavy, and the garment can limits movement. In some cases this can irritate other injuries e.g. spinal injury (KK, 2019).	Post-stroke individuals may be more susceptible to feeling more extreme body temperature changes. Garments are therefore chosen to support a "comfortable body temperature" (VW, 2019), and garment thickness is a key indicator to participants in their evaluation of clothing.	The fit of the garment changes according to the stage of recovery. Initially, the fit is considered in terms of levels of 'comfort'. Later on this may change as the degree of stretch in a garment can be useful for ensuring a good fit to the body, reducing concern highlighted in the category 'Weight of the garment'.
Key Insights	"I was a fan of silk but now I find it slips off [my body] quite easily so I can't wear it" (HH, 2019).	"I already wear a sports base layer. It's like tights material, elastic. I wear it to keep warm because after stroke my [affected] arm can become cold really easily and I struggle to keep it warm. And when this happens it becomes stiff and painful" (VW, 2019); "Ever since my injury I've had higher body temperature so I just wear t-shirts all the time" (PQ, 2019), "Me too, but because of my new medication" (HH, 2019).	"Initially you just want to wear something loose and comfortable. Later on, when you've come to terms with things you're more bothered by what you look like" (GG, 2019); "You don't want a textile that chafes or restricts movement especially when you struggle with that to begin with" (HH, 2019).

'Photographic data' was collected over 18 months from participant observations to demonstrate ranges of styles, reinforcing insights gathered (Figure 3.4).

Figure 3.4 Categorising observations of post-stroke garments and identity (Author's archive)



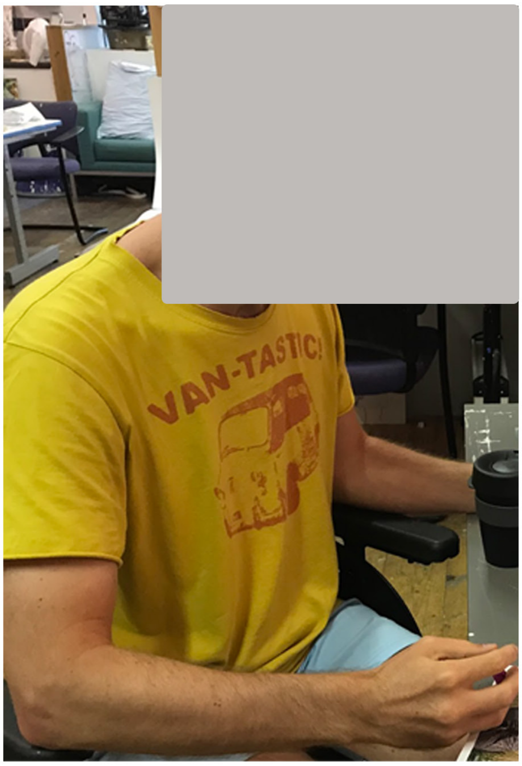


RSEY

gs - easy to pull on

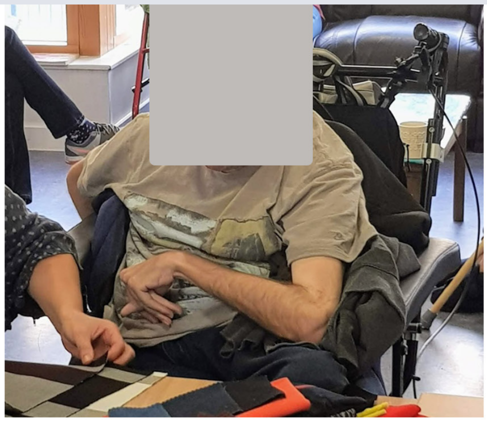
CLASSIC T-SHIRT

familiar/ usual



OVERSIZED T-SHIRT

extra room/ space for the body



POLO SHIRT

sportswear

What became evident from Theme two was a complexity of thoughts that influenced the ability to interactions with the garment have wide ranging impacts.

Table 3.5: Theme 3 - 'Garment: boo

	Factors impacting and impacted b		
	'Roles' and 'relationships'	**Access to public spaces** *(e.g. work)*	**Ability**
Summary	Dressing may require engagement with others (e.g. family/carers). Where dressing is typically undertaken by oneself (albeit for intimate occassions, or when learning to dress as a child), the inclusion of others to aid this process can often change the nature of relationships. This can further impact perception of self and act as a reminder of lost ability.	The dialogue between garment and self can have wider consequences on the orientation of self within society. This may be in terms of ones identity or, in this case, the ability to participate in social and vocational activities. This exists alongside other barriers including feeding oneself.	This is in terms of the i of fatigue during dressi arranging clothes as a re post-stroke deficits. Ho this also includes frustr in the recollection of al i.e. the memory of bein to perform an ADL suc dressing, with ease, ca to the frustration of ina and further dislocate the of self from areas of the which are limited in fun (Table 2.1, Chapter tw
Key Insights	"Brain injury changes you. You have to re-learn who you are all over again and at 42 I really didn't want to be a new person because I'd already found myself in my 20s" (KK, 2018).	"Of course after a few years you learn tricks to be able to wear certain clothes but you might still need help in some areas. Imagine getting stuck in a public toilet and not being able to leave without embarrassing yourself because you can't do up your trousers. So you avoid these situations. It means you are limited and restricted to returning to work" (BD, 2018).	GG states that fatigue directly impacts her abil tie and secure the apron (Figure 3.6): "See this is it's difficult. It tires out m arms" (GG, 2019); "Wh the limb is so heavy you worn out quickly. It take lot of energy and effort t the weaker arm. You wa because you know it's important but it can stop from doing anything else afterwards, even for the whole day because you to rest" (FF, 2019).

o dress. This exists both in the act of wearing and dressing. Findings demonstrated in Table 3.5 that

ly behaviour in the act of dressing’

y garment experience during the act of dressing			
	Garment specification *(Size and stretch)*	**Garment specification** *(Fastenings)*	**Purposely designed wearables** *(e.g. splints)*
mpact ing or esult of wever, ations bility: g able ch as n add ability e sense e body nction wo).	Strategic decisions are often made in terms of garment size and stretch in order to make the act of dressing easier. This may be in terms of enabling the individual to dress with or without support.	The location of fastenings on garments can limit access. Those positioned outside of the ‘range of movement’ can restrict access to dress, requiring support or preventing the use of the garment altogether. Although the fastening may be easily reached, the type of fastening can act as an additional barrier; requiring levels of motor ability or strength that the individual does not have.	Conversations with participants resulted in a different perspective; considering the opportunity that garments have to influence ability, support, health and wellbeing; especially within public spaces. The use of garments as [health]care aids or devices is not new. Section 3.2.3.2 explores this further.
ity to n why ny en get s a o use nt to o you e need	“People wear one size up after injury because it’s easier to dress in, there’s more room” (QR, 2019); “Stretchy is good to move in and dress in, but too much stretch is difficult because you can’t push your arm through. But non-stretch is also an issue too because there’s no give” (YZ, 2019).	“At home and in public I now wear simple clothes. No buttons or zips. It’s easier to dress myself. My bra is the only thing I wear that has a fastening, probably because I have no choice about that” (KK, 2018) Notably, conversations began to directly address issues with garment specification (Figures 3.1 and 3.2), considering how adaptations to garments may be made in order to make them accessible: “I’ve put Velcro on the design (Figure. 3.7). Just down front with buttons on top which make it look like a cardigan or something. But because you have velcro you can take it off easily” (AC, 2018).	“If it takes too much effort to put on, or if it’s uncomfortable then it’s not going to help” (AB, 2019). “Yeah it helps if you want to wear it, like if it makes you look good. That’s a bonus, because it can be difficult to feel good about yourself when you look and move differently” (ST, 2019).

The thinking that surrounds conversations with participants regarding garment specification takes the p clothing to *"camouflage the unconventional"* (Radvan, 2013) and differently abled. Using 'discrete' fast *dressed easier and allow both children and adults with disabilities to have independence and feel great ab* that it is not inclusive to provide the ability for everyone to access the same fashions, but that, to be tr should be carefully considered to avoid stigma.

However, Inclusive Design is defined as *"design which is usable by as many people as reasonably poss* Standards Institution, 2005). Therefore, it can be argued that adaptive wear is not entirely 'Inclusive'. A first instance, for the 'abled'. Or in fact, that fashion should in the first instance consider diversity in use fashion industry (Hernandez, 2000; Chowdhary, 2002; Carroll, 2009).

Figure. 3.6 Dressing demonstration (Author's archive)

position of using pattern adaptation (Hernandez, 2000) and the creation of 'specialised' ranges of enings to appear 'normal'. For example, the Hilfiger line (Tommy Hilfiger, 2020) aims to *"make getting out themselves"*, suggesting that this otherwise isn't the case (Tommy Hilfiger, 2019). This is not to say uly inclusive, the lines should not be separated from the mainstream and the language used to market

sible to the greatest extent possible without the need for special adaptation or specialized design" (British case may be made that those who are disabled should not need to conform with fashions made, in the . Conformity via concealing the presence of disability is notably a common theme within this area of the

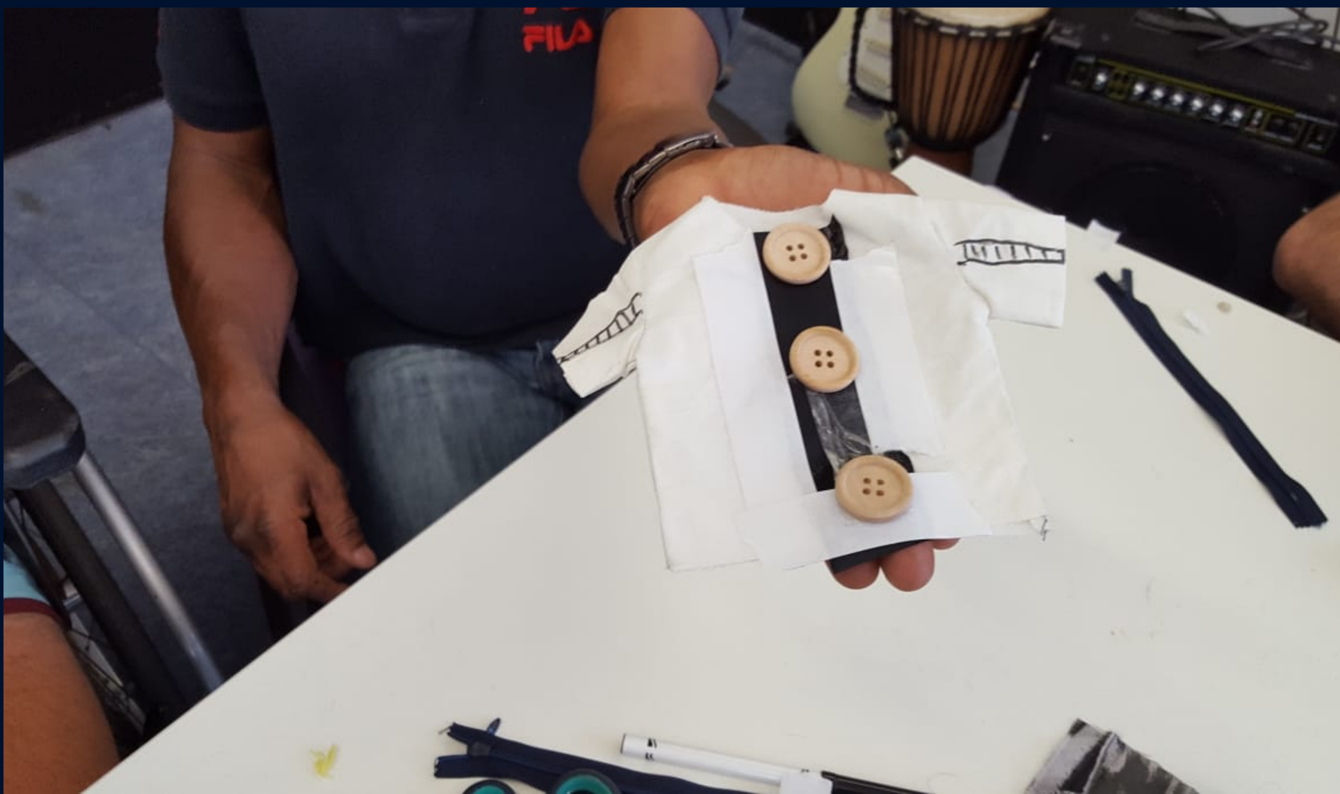


Figure. 3.7 Participant sample: Rethinking fastenings and garment adaptations
(Headway, 2018; 2019; Author's archive)

Figure. 3.11 Oedema sleeve (participant photo from Author's archive)

"Why would people give you something like that! For one I couldn't get it on and secondly it looks awful! It's like they're trying to make you look horrible so no one will go near you. There's more support for how cancer treatments affect you and your identity, but there's nothing with stroke. Stroke is still in the dark ages" (FF, 2019).

Figure 3.12 Oedema glove (given to researcher from a participant; Author's archive)

The nature of the material choice, colour and visual aesthetics of medical aids was significant in the case study:

Participant (ST):
"My shoulder [is injured]. I have a sling. [...] You can either slide it on or open it with the velcro, but the velcro is a pain in the neck. So I've [prepared the velcro and] got it how I want it.

Acupuncture helps but I wear this to bring it in. [...] but I don't like wearing it here [support group] because people go "ooh what's that you got" and I'm like ugh [do I have to answer those questions]."

After further conversations around this, the participant (ST) was asked by the support worker (SW) how he would feel if changes were made to the aid:

Support Worker (SW): "What if that could look 'normal' or 'fashionable'?"

(ST): "What you're saying right now [is making me] really want to cry"

(SW): "So it's that important to you?"

(ST): "Yeah because inside I'm hurt, I'm hurt inside places that nobody knows. I don't want to show it. It's not that I'm frightened of it, it's just that constant 'ooh' [sympathy]. I've had four years of it, I don't want it anymore. I'm in that thought that I'm not right and I don't want to think about that"

A detachment from 'treatment' or concealing an 'aid' or device is preferred in order for individuals to avoid attracting further stigma or conversations of their 'otherness'. *"When people see you wearing the aid on a regular basis, it becomes part of you, how they see you"* (AA, 2019). They become known or recognisable by their health status made more visible and distinguishable by the wearable device. There is often a failing to acknowledge the *"person within the body"* (WW, 2018) instead focusing on the disability, dislocating the person from their 'disease'. Signs of stigma continue to be used to highlight bodily signs of physical disorders, attracting attention, a novel stimuli (in this case the wearable) to which a natural curiosity is drawn towards, and is highly regulated by society (Garland-Thomson, 2009).

Looking or appearing different is resisted in attempts to conceal or draw attention away from the affected area(s) or appear 'normal'. This is evident in the visual form of the wearable and even, for example, in the expectations of a garment: *"I like the look of buttons because it's adding a familiar look. It would be boring if it didn't have that. To me it's like decoration because I don't use them. It's just a case of a garment looking right"* (KK, 2018).

Thoughts from Pullin's manifesto (2017) exploring material aesthetics are particularly useful here. For example, the 'skin tone' colour of oedema aids attempts to emulate the natural colour properties of the limb. However, such attempts to emulate the 'hyperreal' often fail to distract, instead appearing more 'alien' as the 'human' qualities of the limb fail to be successfully captured in a non-human form.

Contrary to this, approaches towards the construction of the purposely artificial and eye-catching, highlighting the disability rather than attempting to conceal, takes a ‘shameless’ stance, fueled by the social model (Oliver, 1996; Garland-Thomson, 2005; Davis, 2006). The prosthesis or aid is overtly non-human and, depending on material composition, may also deliver advances and extensions of human ability. Within the case study, participants discussed the need to generate awareness and highlight their disability by expressing this through t-shirt designs (Figures 3.13). Positive messages were central to this:

“People either don’t acknowledge you or they treat you differently. People need to understand what it is like and how the other person feels. I’ve used a slogan to express who I am and I’ve put some softer materials on it to encourage people to hug you. You can really miss the social contact when you’re disabled” (AA, 2018)

Figure. 3.13 Knowledge exchange through the making process: Photo compilation of T-shirt exercise (Headway, 2018; 2019; Author’s archive).

In reaction to this polarisation of ‘hyper real’ and ‘artificially unfamiliar’, Pullin advocates for a ‘nuanced alternative’, a ‘Super Normal’ integrating disability into the everyday suggesting *“that disability [should be seen as] part of the fabric of everyday life”* (2017: 1). Disability designed wearable objects are considered *“artificial yet familiar; self assured yet understated; unapologetic yet unremarkable”* (ibid). This *“Super Normal”*, proposed by Fukasawa ([2006], 2007) aims to design ‘things’ that embody and epitomise ‘ordinariness’, using ‘everyday materials’, e.g. wood and leather (Figure 3.14). The material choice is key in challenging *“a crude common conception of design: [...] something added, distinct, noticeable”* (Pullin, 2017: 3) instead fitting *“into our everyday lives, to become an unremarkable part of the whole”* (ibid).

Figure. 3.14 ‘Super Normal’ materials for prosthesis: ‘Hands of X’. (Pullin et al., 2019)

Advances in smart materials are providing opportunities to intervene within the area of wearable medical devices and aids. From the commercially available ‘Soundshirt’ (Figure 3.15), demonstrating the potential for wearable technology to influence quality of life; to the speculative ‘Power Suit’ (Figures 3.16 and 3.17; The Future Starts Here, 2018) present active research exploring the use of garments in health and wellbeing. ‘E-textiles’ in particular display ranges of functions including, but not limited to, signal processing (Marculescu et al., 2003; Carey et al., 2017), communication (Post and Orth, 1997; Singh et al., 2016; Grabham et al., 2018), sensing and actuating (Katragadda and Xu, 2008; Michael and Howard, 2017; Hughes-Riley and Dias, 2018).

Figure. 3.15 The Soundshirt. (Cutecircuit, 2019)

Figure. 3.16 The Power Suit: Prototype (Fuseproject, 2019)
Left: Back; Right: Full body view

The 'familiar' notion of the garment is considered useful, engrained within the everyday. A tool that, as has been demonstrated, can be stigmatising, concealing or 'ordinary'. However, issues concerning the suitability of material behaviour and properties to the 'wearable context', 'user-friendliness' (Yang et al., 2018), ethical concerns and privacy issues (particularly concerning monitoring and data collection methods) continue to be persistent barriers to adoption within the wearable technology sector (Catrysse et al., 2007). In addition, the complexity of cultural, behavioural and health-related characteristics involved in the act of 'wearing', in the most part, fail to be addressed.

Early examples of 'embedded electronics' (Catrysse et al. 2007) such as the ICD+ suit from Philips and Levi's (Aarts and Marzano, 2003) and the ' Lifeshirt' from Vivometrics (Wilhelm et al., 2002) required either the removal of sensors or were not washable. Significant advances have been made since this time for both the washability and flexibility of components. The development of conductive yarns enabling the formation of textile sensors and electrodes (Yang et al., 2018) have influenced new applications of electrocardiography [ECG] (Catrysse, 2004; Pirotte et al., 2005), electroencephalography [EEG] (Wei et al., 2017) and electromyography [EMG] (Belbasis et al., 2015) monitoring into wearable textile formats.

Advances can take numerous decades to become available for commercial use. Conducting polymers, for example, were first discovered in 1862 (Dinh, 1998) when Letheby *"attained a partly conductive material"* via the oxidation of aniline in a sulfuric acid solution (Ala and Fan, 2009: 51). Issues with processability, *"insolubility, an infusible and brittle nature, and the lack of air stability [...] prevented the integration of these conductive materials into new application areas"* (ibid: 51-52) including textiles.

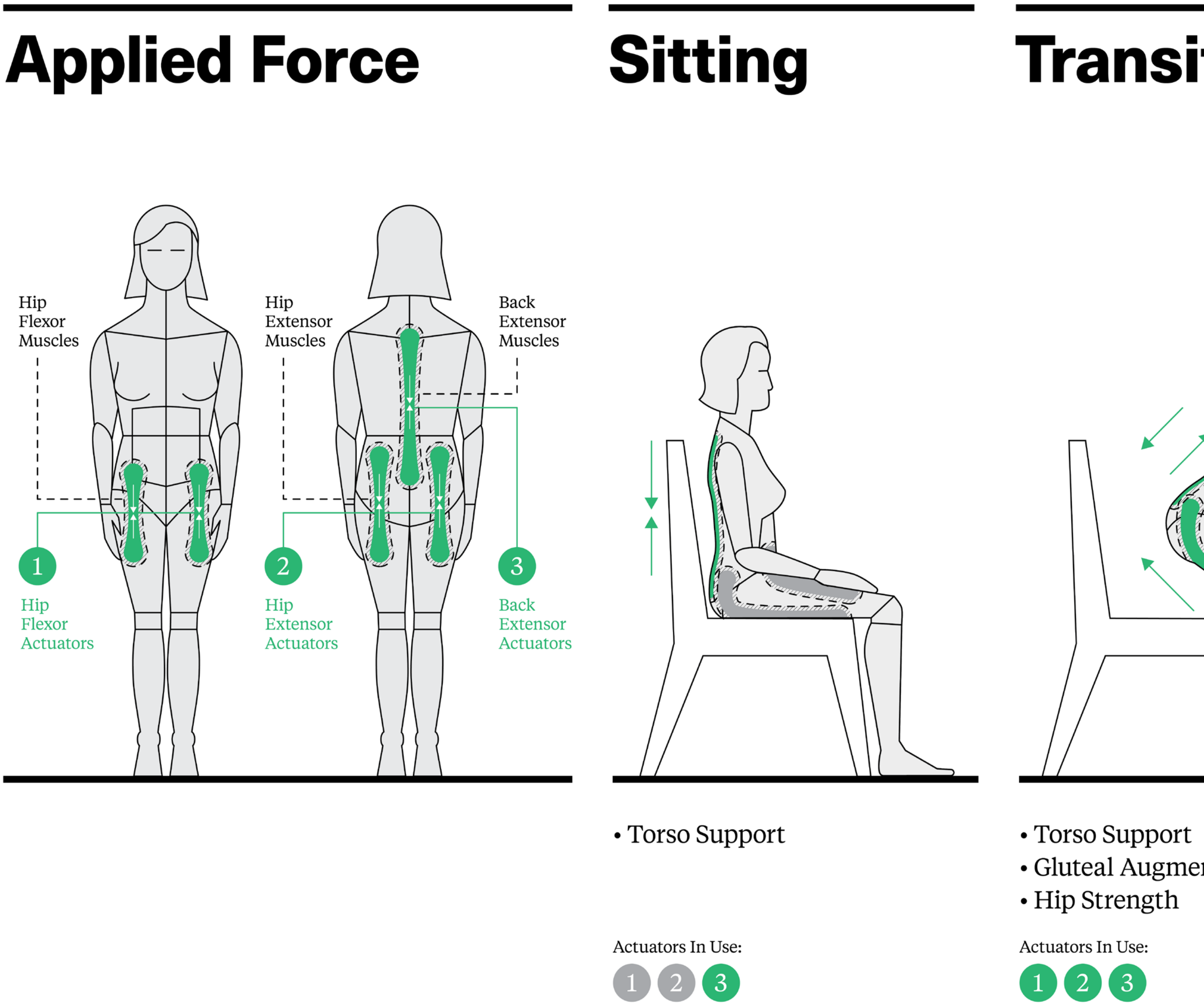
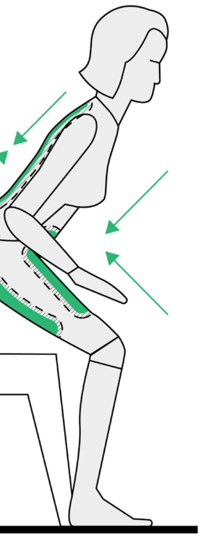


Figure. 3.17 The Power Suit: Summary of function (Fuseproject, 2019)

Yet 'wearables' are used in numerous current approaches within stroke rehabilitation (Figure 3.8 to 3.10) it is considered that their impact is not fully realised. Findings from this Chapter present a need to cons impact. It is hypothesised that increases in frequency, duration of contact and desire to interact with reh

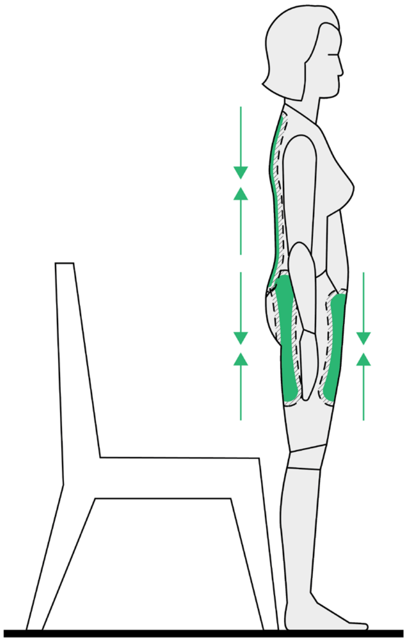
1) The close fitting, intimate contact the garment has with the wearer (Van Langenhove et al., 200
2) The duration of contact the garment may have as a routinely worn 'device', increasing levels of
3) The 'mobile' nature of the garment in which it is able to transgress time and space
4) The appeal of the garment which can be tailored to context, mood, desire and need;
5) The manner in which the garment is a universally and intuitively understood 'tool' by key stakel

tion



ntation

Standing



• Torso Support
• Gluteal Augmentation
• Hip Strength

Actuators In Use:

1 2 3

Power Assist

Core strength naturally declines as we age. The Power Suit augments your strength by aligning electric muscles with your natural muscles, actuating at the same time to assist your movement.

), both commercially (Saebo, 2020) and in research environments (Yang et al., 2018). However, sider the 'everyday', supporting care beyond 'confined environments' in order to have greater abilitation methods could be achieved by utilising garment properties including:

7);
f engagement;

holders[4].

[4] Given that the garment is already used within occupational therapy in the retraining of dressing as an ADL, the use of the garment as a tool in the rehabilitation system of care may be somewhat easily integrated into existing systems/ patient pathways (Stockley, 2019).

3.2.4 Chapter summary: Identifying key challenges and opportunites for using the garment as an interventional/ therapeutic tool

After revealing issues about identity and behaviour post stroke through utilising the garment as a design probe, this chapter introduces the link between using garments as a therapeutic tool for stroke rehabilitation. Taking into consideration findings from prior chapters, it is considered that the garment has the potential to become an enabler and mediator of the following factors in stroke recovery:

1. Improving dose via qualities of the garment such as the level of contact a garment holds with the body throughout the day and its ability to transgress time and space;
2. Improving adherence/ compliance to a treatment. The level of integration into daily routine and lifestyle choices is considered important to reduce levels of disruption when trying to rebuild life (HH, 2019). Additionally, the perception of the treatment by the self and others in a manner that minimises attention towards the 'disability'/ treatment process outside of clinical environments. This depends on the manner in which the treatment is integrated into the garment.
3. The above points are then considered to impact quality of life and level of independence.

However, this chapter has also demonstrated that there exists many challenges in positioning a garment in this way:

The level to which garments are perceived as social signifiers (Bourdieu, 1984; Wilson, 1985; Skeggs, 1997; Crane, 2000) causes challenges when integrating a new functionality, particularly around disability. As Chapter two has demonstrated, the disabled body has long been concealed and excluded from 'the norm'. This chapter has demonstrated how, in drawing attention towards a disability by the presence of a wearable aid, this sense of 'otherness' can be exasperated and causes others to direct questions towards the individual that can trigger negative memories and associations of the injury. This acts as a reminder to the individual of an 'otherness' and deficit (ST and AA pp.125).

However, drawing upon other aspects of identity rather than the disability can counter this to some extent. This approach can still be problematic; in turning attention away from the disability, this could further conceal disability from society, fueling issues of misrepresentation and the hiding away of 'otherness'. It requires careful consideration for how components and additional functions are integrated into the garment that stay true to the individual, without causing distress (see Chapters four to seven).

Findings from studies in this chapter have also demonstrated that personal identity and the social self can be a factor affected by stroke. The manner in which people perceive and treat you (AA, pp. 126). The inability to wear the same clothes as before the stroke, removing choice of self-expression (HH, pp.113).

There are many factors attributed towards capabilities and the capacity to dress post-stroke, which has a direct impact on what individuals can wear. Factors include fatigue, limiting the degree of engagement in dressing and other activities leading individuals to choose garments that are easy to dress in with minimal energy (GG, 2019). Garments that hold a degree of stretch are considered "good to move in and dress in"

(YZ, 2019). But “tighter” stretch garments that have a high level of elastic recovery can prove difficult, requiring higher effort to push the body through the garment (ibid).

Other challenges regarding limited garment choice also exists in the act of wearing the garment and keeping it positioned suitably on the body. A lack of movement or change in posture (e.g. dropped shoulder) can result in straps falling off (JJ, 2019) or, depending on the textile (e.g. silk), the garment can slip around and off the body. Garments that require constant adjustments, and/or adjustment in areas difficult to reach, can be inaccessible.

All of these factors limit the garment specification that the intervention is integrated into, and therefore can result in a stereotypical garment that looks like a purposely-made disability garment which individuals do not desire to wear.
Further work needs to be done to explore how we can retain a diversity in garment styles and textile structures to be able to create garment-based therapeutic ‘devices’ that individuals want to wear and therefore comply with the treatment embedded within the garment itself. Having said this, the presence of the intervention and indeed the type of intervention present in the garment can limit this compliance. Chapter four will introduce three small case studies exploring this topic area. Each case study will explore methods of integrating three types of rehabilitation; firstly, the existing method of constraint induced movement therapy (CIMT); secondly, using textile properties to navigate movement via haptic responses; and thirdly, re-thinking e-textile properties for the application to de-weighting the limb (a particular barrier for engaging voluntary movements and therefore engaging in training).

CHAPTER 4.0

Embedding rehabilitation into a garment: Three case studies exploring the use of the garment as a therapeutic intervention

4.1 Chapter 4.0 Overview

This chapter evaluates the positioning of the garment as a therapeutic intervention for stroke, specifically evaluating how the type of intervention and presence of an intervention can limit use of a wearable therapeutic device. Since the impact of an intervention is influenced by the type of intervention and impact on recovery, the chapter will outline this in three small case studies. Commentary on user experience is used to assess the limitations of each concept.

Insights from Chapters one, two and three are reflected upon throughout the sampling process, in which the garment moves from being a research tool for eliciting conversations around the body to being explored as a tool for intervening. Correspondence between transitions, boundaries and constructed hierarchies within the space where the garment merges roles with medical devices are brought forward.

Technical considerations for fulfilling the concept are included to a degree. However, since the studies are not taken forward, in-depth analysis was not included. Instead user experience is considered more influential at this stage of evaluation since learnings from user behaviour can determine compliance of use within further developments. Compliance of use and indeed, continued use is a core part of recovery, as demonstrated in Chapter one.

Iterations of alternative functions and types of rehabilitation that are embedded within the garment are investigated. This Chapter will explore the garment *"within 'active' and 'passive' states in rehabilitation (active whereby the individual is consciously engaged, and passive when rehabilitation occurs alongside life)"* (Salisbury et al., 2019).

A focus is initially placed on sampling textile structures[1], combining multiple yarn behaviours to realise three small case studies, each developing from the latter;

1) 'CIMT' (integrating Constraint Induced Movement Therapy, by way of 'forcing' use of the affected limb);

2) 'Navigating movement' (using the changing fit of the garment to navigate and guide movement);

3) 'De-weighting the limb' (manipulating the fit of the textile to reduce the weight of the limb).

The following chapter provides a summary of the key insights from Salisbury et al., 2019; a paper which discusses the use of the garment as a research tool and medical device, presented at the Design Museum and published in the proceedings.

[1] Some sample investigations are supplemented by a range of videos. To view, scan the QR codes in each figure. Supplementary data can be found in Appendices 2.1 and 2.2.

4.2 Case Study I: Embedding CIMT into a garment

4.2.1 Justifying the use of CIMT

Constraint Induced Movement Therapy (CIMT) is widely used within stroke rehabilitation and has substantial evidence of efficacy for individuals with long-term stroke disabilities. CIMT was chosen due to the evidence base[2] which surrounds this method available with the Cochrane Library (Pollock et al. 2015), but also as a method which identifies the need for use of the limb and an active self.

The method purposely restricts the use of the unaffected limb in order to 'force' the use of the affected limb within *"intense functionally oriented task practice"* (Wolf et al., 2006: 2096) to encourage the use of the paretic upper extremity in everyday life (Taub et al., 1993).

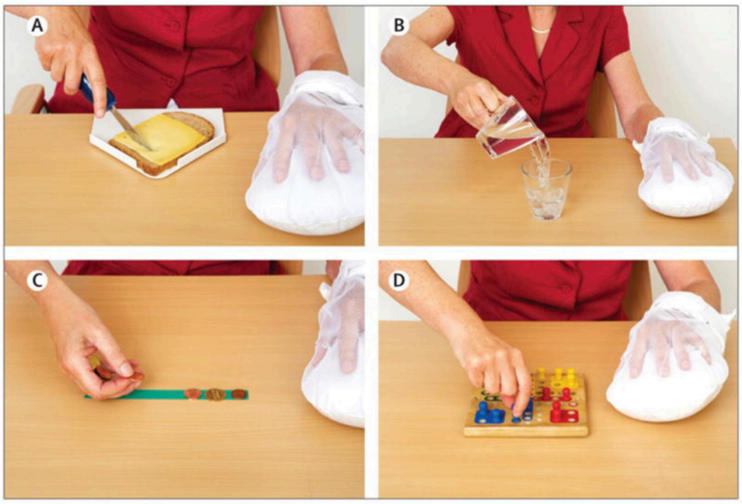


Figure. 4.1 Example of CIMT tool: 'Mit'. (Kwakkel et al., 2015)

The unaffected limb is typically restricted (including, in some cases, the trunk) by means of 'casting' it into a splint or anchoring it down to a table with a weighted mitt (Figure 4.1), to prevent its use. The equipment is used to further disable the body in order to enable recovery. Sample investigations consider how a garment may inflict similar levels of restrictions to body movements in order to provide the same therapy in a public facing context.

4.2.2 Method

Circular knitting was used to construct small samples (Figure 4.2) to compare the degree of flexibility and levels of comfort as a result of yarn content. Additional samples were tested combining Pemotex with wool and nylon monofilaments (Figure A2.21[3]) using a lino weave, later creating a toile (Figures A2.22 and A2.23[3]).

[2] Although neurodevelopmental techniques (Bobath, 1978) "have been shown to be efficacious in control studies" (Wolf et al. 2006: 2096), the integration of repetative training into methods with task-oriented approach holds evidency of efficacy among individuals "who retain some ability to actively extend the fingers and wrist of their paretic upper extremity" (Barreca et al., 2003; Duncan et al., 2005; Wolf et al., 2006).

[3] Appendix 2.2

Jacquard weave was used to construct a twill with Pemotex and cotton (Figures A2.24 and A2.25[3]), replicating the spacing used in the lino weave. The spacing was chosen so that the changes in textile behaviour (shrinking) were visible.

Twill was chosen versus circular knitting since it delivered reduced stretch and therefore increased restriction, particularly suitable for the intended application. Small samples were scaled up into a jacket (Figure 4.3) within the concept film (Wearing Your Recovery 3.0, 2018). Whilst *"the jacket's visual composition was created purposely for the film to exaggerate the change in behaviour of the textile, as well as giving a nod towards the flamboyant personality of [the participant] and their pre-stroke career"* (Salisbury et al., 2019).

Figure. 4.2 Yarn combinations. Left to right: Pemotex with elastane (2:1 ratio), Pemotex with polypropylene (1:1 ratio) pure Pemotex. (Author's archive)

4.2.3 Limitations and considerations of Case Study I

The sleeve's circumference was manipulated in size and stretch in order to restrict movement by using yarn (Pemotex[4]) that holds the capacity to shrink in response to heat stimuli (Figure 4.3). After applying heat the sleeve stiffens increasing the 'hold' of the garment onto the unaffected limb, restricting movement; *"inflicting a behaviour upon the body - rather than working with it, it works against it"* (Salisbury et al., 2019). Some discomfort was felt through the tightening of the sleeve (FF, 2019) but this can be controlled *"either at source, through the controlled emittance and distribution of heat or by altering the textile composition"* (Salisbury et al., 2019).

The level of stiffness was important to control in order to retain levels of 'comfort' in wear. Adding wool or cotton softens the overall rigidity of the textile post shrinking. Whilst adding elastane (Figure 4.2: Left) introduces stretch which is 'toughened' by the use of Pemotex, allowing for some 'ease' to a typically stiffened, solid textile as in the case of pure Pemotex (Figure 4.2: Right) which appears to have an almost non-woven quality post shrinking. Where the addition of elastane to the textile may not completely restrict movement, movement requires higher levels of strength and energy to move the limb therefore generating a level of restriction that is still effective but also comfortable (FF, 2019) and possesses qualities of textile behaviour that is 'familiar' in the context of everyday garments, unlike that of pure Pemotex.

Changes in textile behaviour, as a result of shrinking, impacts garment aesthetic (Figure 4.3); visualising textile functionality and highlighting a difference to other garments.

Forcing the use of the limb via CIMT does not mean that the movement executed is one that is completely devoid of other compensatory strategies, such as moving the trunk of the body to compensate for lack of limb extension. The function of restricting use of the unaffected limb may also be disruptive during everyday use. More often, individuals report not knowing how to use the limb, requiring guidance for performing movements (HH, 2018) which was of greater concern to participants. A level of guidance or navigation for executing movement may be more valuable in the absence of a physician, in the context of self-care.

[4] Shape memory polymers (SMPs) may be used instead of Pemotex, to utilise the benefit of tightening and loosening hold, making use of SMPs reversible qualities. Due to cost limitations, Pemotex was used for the purposes of this early study. See Appendix 2.1 for a list of yarn specifications.

Figure. 4.3 Stills displaying the translation of the embodiment into a jacket: A concept film. (Wearing Your Recovery 3.0, 2018)

4.3 Case Study II: Navigating movement

4.3.1 Contextualising Case Study II

Building on the previous sample findings, the following concept asks how we might use the garment to navigate movement away from compensation, towards 'quality' movements? In particular, how might the shape and change in behaviour of the textile, from a flexible, free-flowing form to a more rigid, less flexible form, provoke or disrupt a particular movement, by drawing attention towards the 'error' made by the individual. Would that enable them to recognise and 'correct' or attempt to correct such movement? How does this affect the experience of the garment and the mood of the individual?

Earlier findings demonstrated that there exists a need for individuals to be more informed about their recovery process: *"I need to know when I'm overdoing it"* (BC, 2018). But more so for executing 'quality' movements in the absence of a physiotherapist and avoiding injury (HH, 2018):

Participant (HH):

"How do I know how I'm doing when I'm on my own doing exercises by myself? When I'm not with my physiotherapist it's really difficult to know if I'm doing something [a movement] correctly.

In my mind I think I've not done much so I end up doing more and overdoing it and tiring myself out. It would be great to have a reminder to know if you're doing it [movement] right and to know when to stop."

Support worker (SW): "Or to remind you that you haven't done any today?"

(HH): "Or it tells you to go slower and stop to resist overdoing it. And to tell you how to do something.

But you would want the 'notification' to be felt so that you know but no one else does and so that you can know instantly [whilst doing the movement] instead of having to look at your phone or whatever."

Therapeutic garments and approaches to integrating wearable technology for the purpose of adjusting posture (Figure 4.4) or in supporting individuals to *"relearn how to use the body"* post-stroke (Jessica Smarsch, 2020) have been explored before (Figure 4.5). The Connextyle sensor shirt utilises existing electronics and textile components, including laminated sensors (Figure 4.6), to monitor body movements and provide feedback to guide exercises. There is a lack of consideration for the housing of components in plastic

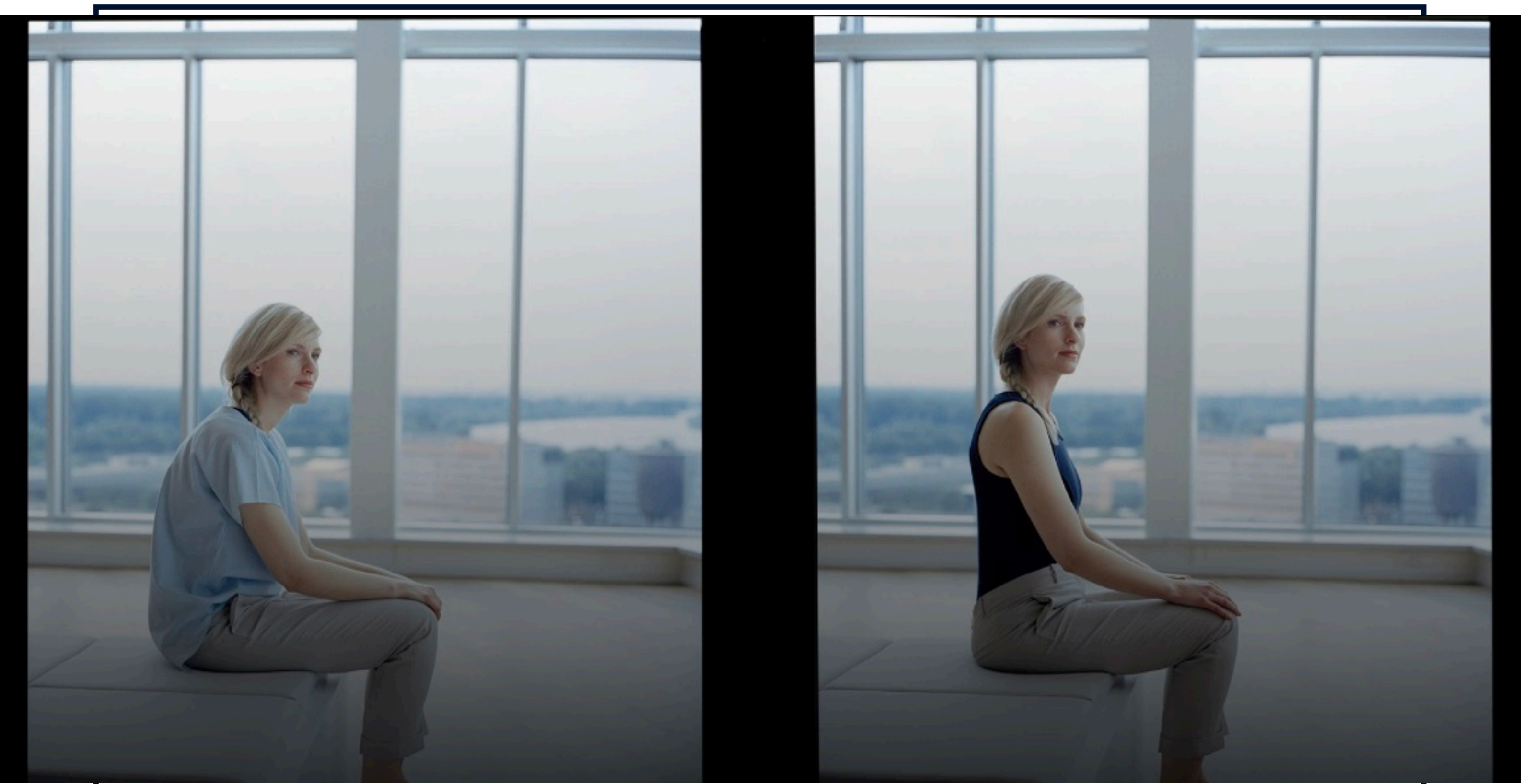


Figure. 4.4 FysioPal: pictoral demonstration of impact.
Left: without vest; Right: with vest (Pauline van Dongen, 2020).

Figure. 4.5 A close-up of power source on
'Connextyle' garment (Jessica Smarsch, 2020).

casings (Figure 4.5), which could be easily incorporated into garment components which already exhibit rigid behaviours (e.g. buttons) and have a purpose beyond housing the components. Although Smarsch considers the social impact of body image, the cut and style of the garments may be seen as being less suited to the needs of stroke survivors (explored in this thesis within Chapters three and nine). The connection between the garment and software limits the scope of the concept for freeing the body beyond the confines of ‘therapy sessions’; since the wearer is required to engage with the programme. The diagram below (featuring Figures 4.7 to 4.10) summarises further examples of approaches for self-administered/ ‘at-home’ care, all of which display similar limitations in the engagement by utilising gamified software programmes.

Similar ‘at-ho

1. Garments
Connextyle *(Figure 4.7)*
Mapping and visualising movement via sensors and simple shapes on an app.

2. VR
Immersive Rehab *(Figure 4.8)*
Often used in conjunction with FES or de-weighting devices
(see Section 4.4).

3. Teleme
(Mountain
Virtually co
patient to

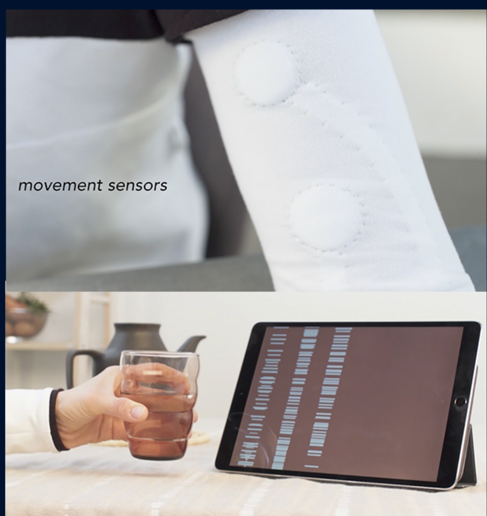


Figure 4.7 Top: close up of ‘invisible’ movement sensors integrated into the garment; Bottom: Screen display of upper limb movement data captured from the sensors (Jessica Smarsch, 2020).

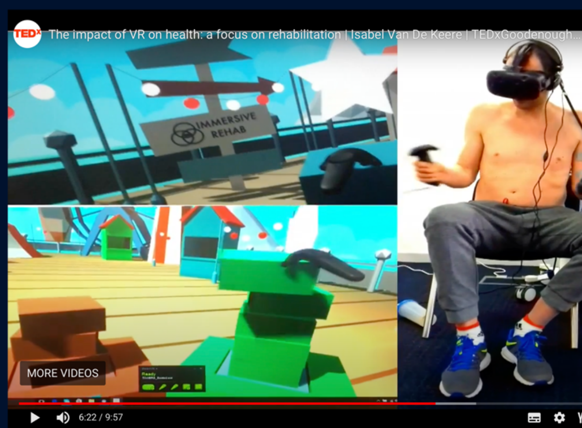


Figure 4.8 Screenshot of VR device: Left: Screens seen by participant; Right: Partic during the therapy (Immersive Rehab, 20

The following sample investigations in this chapter therefore explore an alternative approach; via haptic responses, similarly to Figure 4.4, but rather, delivered via the manipulation of textile behaviour.

Figure. 4.6 Obtained sample. Conductive transfers (Wearable Technology Show: Conductive transfers, 2019; Author's archive).

ome' methods

edicine

et al. 2010)
onnecting a
a clinician

cipant
20).

4. Rehabilitation tools

i. Neuroball
(Figure 4.9)
Used in conjunction with gamification methods, in this case via an app.

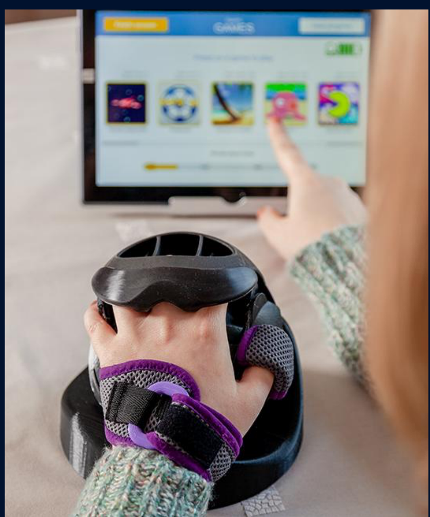


Figure 4.9 Close-up of participant using the Neuroball (Neurofenix, 2020).

ii. GripAble *(Figure 4.10)*
However, it should be noted that this method is more about increasing grip strength than navigating movements.

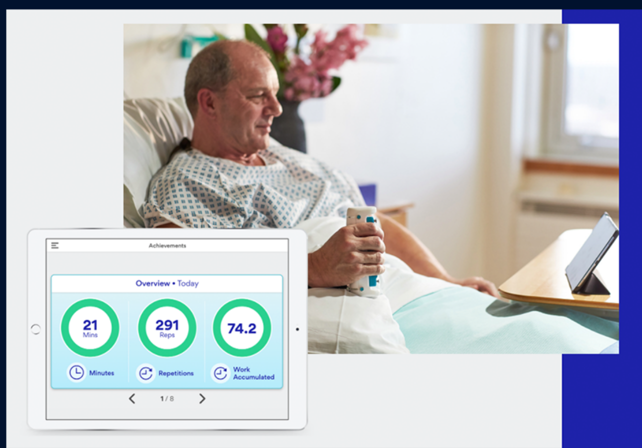


Figure 4.10 Inset: example of data generated by GripAble; Main: Participant testing the device (GripAble, 2020).

4.3.2 Method

Changes to levels of stiffness and softness of the textile explore the controlled changes of the garment shape and form so as to influence the shape of the limb (Figure 4.11 and Figure A2.26[5]). Pemotex and Polypropylene (heat shrink yarns) were used interchangeably, in order to see if participants responded differently to each[6].
Since it was not possible to integrate the heat shrink yarn into existing textiles within these early enquiries, a new (lino weave) textile and ribbon[7] was created (Figure 4.12) and applied via applique onto base fabrics (Figures A2.27 to A2.29[5]). The ribbon/ textile was then topstitched onto textile substrates (Figures 4.13 and 4.14) to observe the physical changes to the textile's appearance; later implementing an embroidery technique (Figure 4.15 to 4.17).

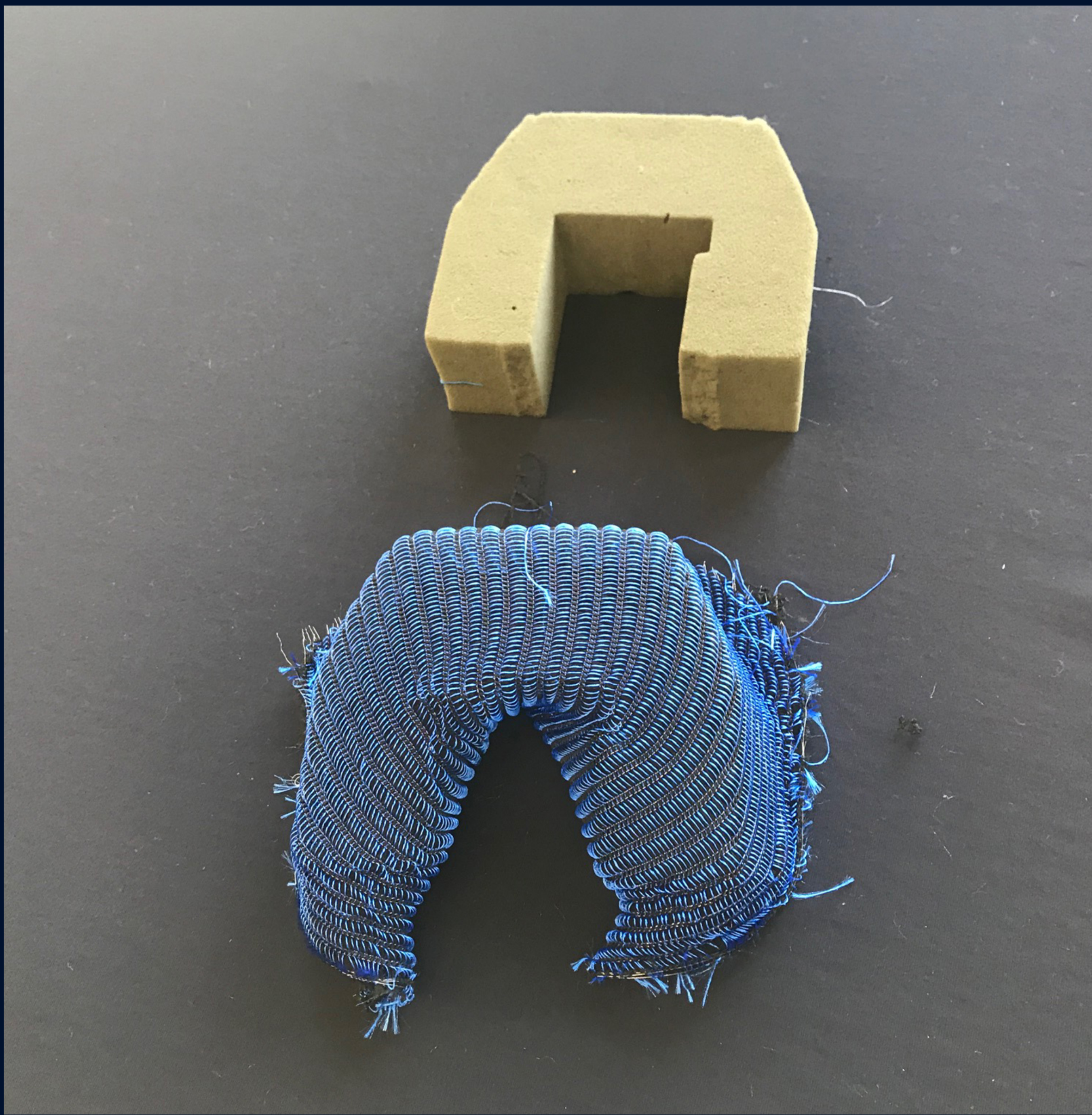


Figure. 4.11 Manipulating the shape of the textile: Study observations (Author's archive)

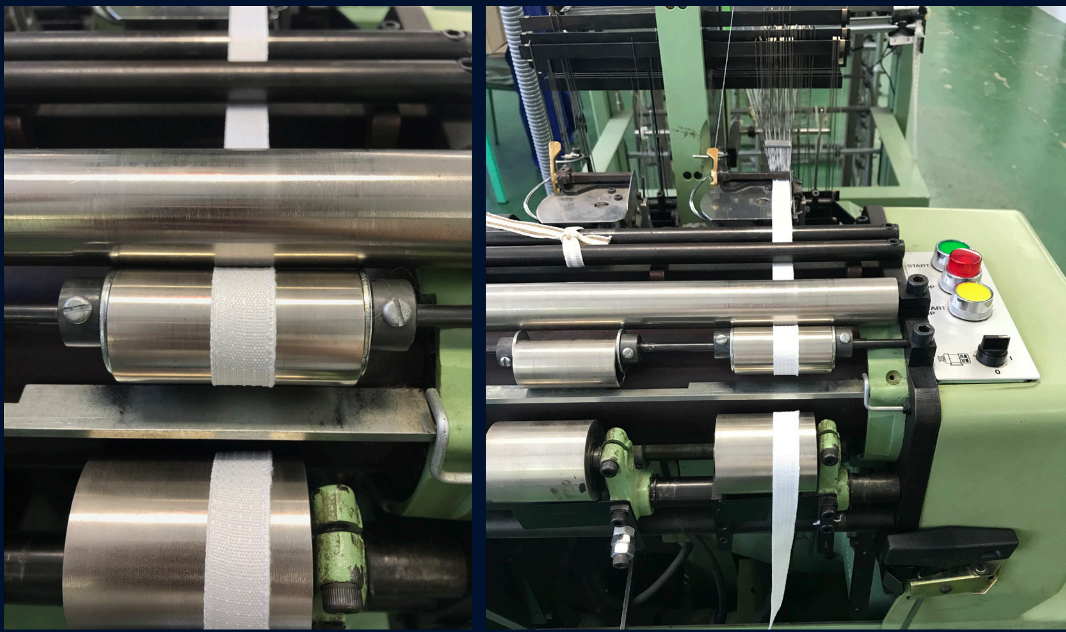


Figure. 4.12 Creating Pemotex:cotton ribbon.
(Author’s archive)

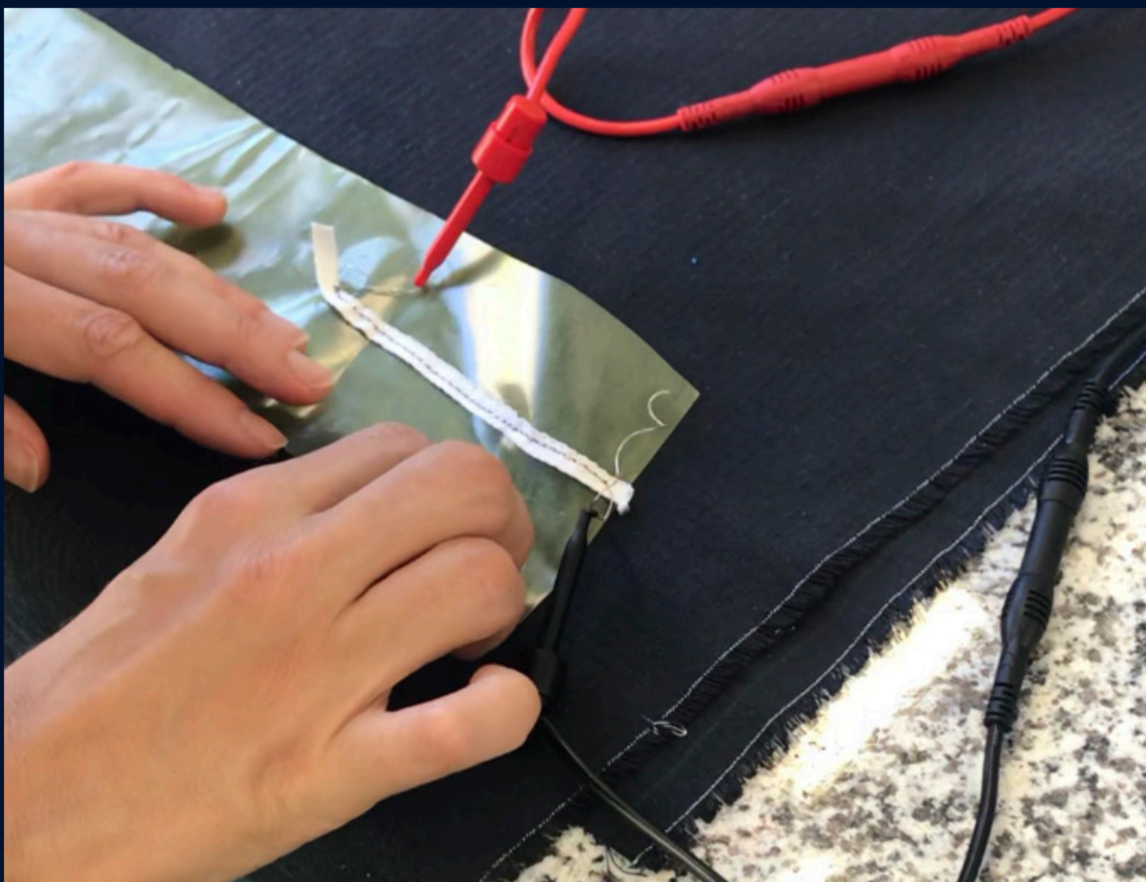


Figure. 4.13 Pemotex ribbon on bioplastic: Connecting to power source
(Author’s archive)

[5] Appendix 2.2.
[6] Polypropylene was observed to exhibit significantly less rigidity and a greater level of softness in its pure form, in direct contrast to pure Pemotex (Figure 4.2).
[7] At a ratio of 6:24, Pemotex: cotton.

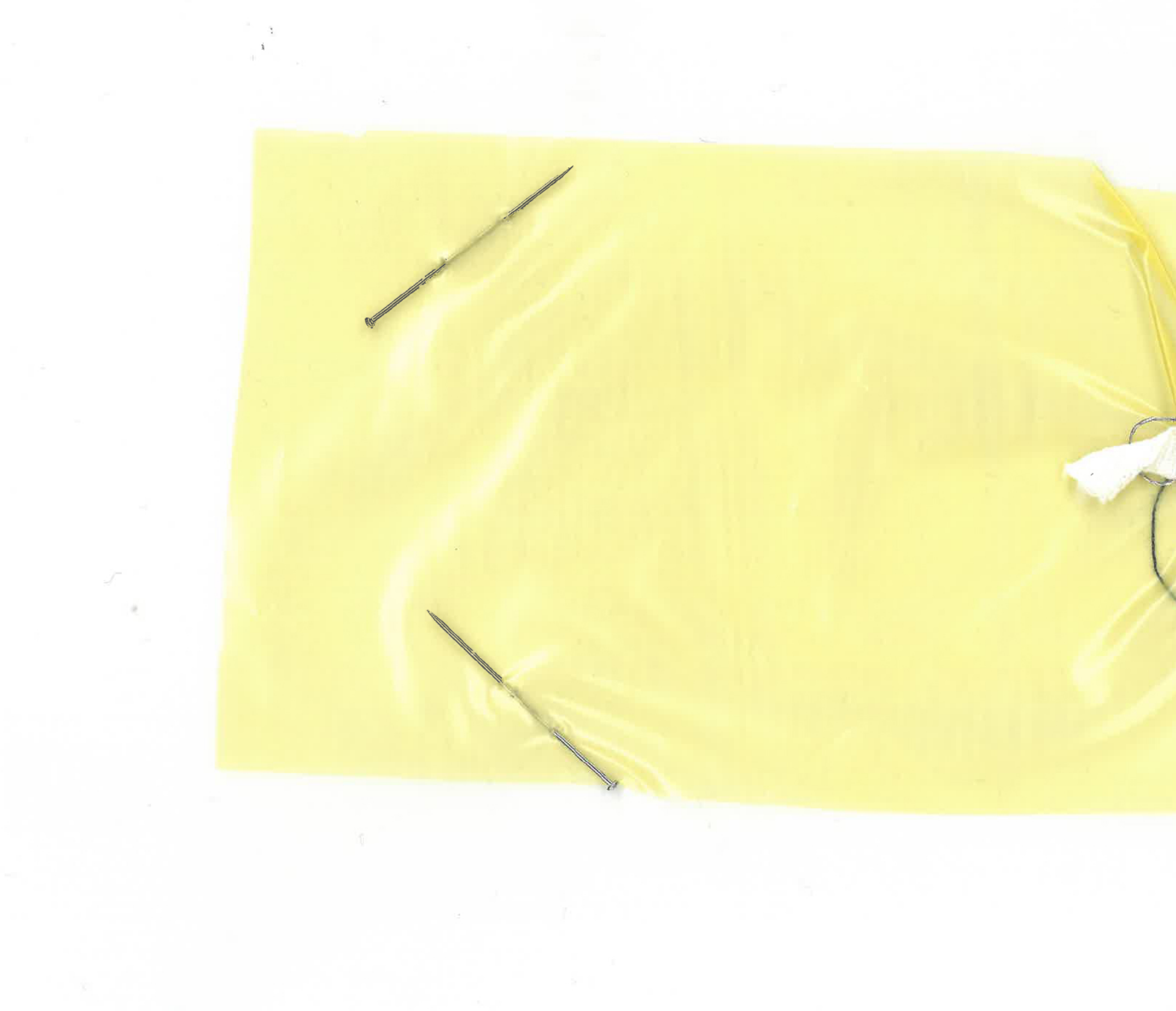
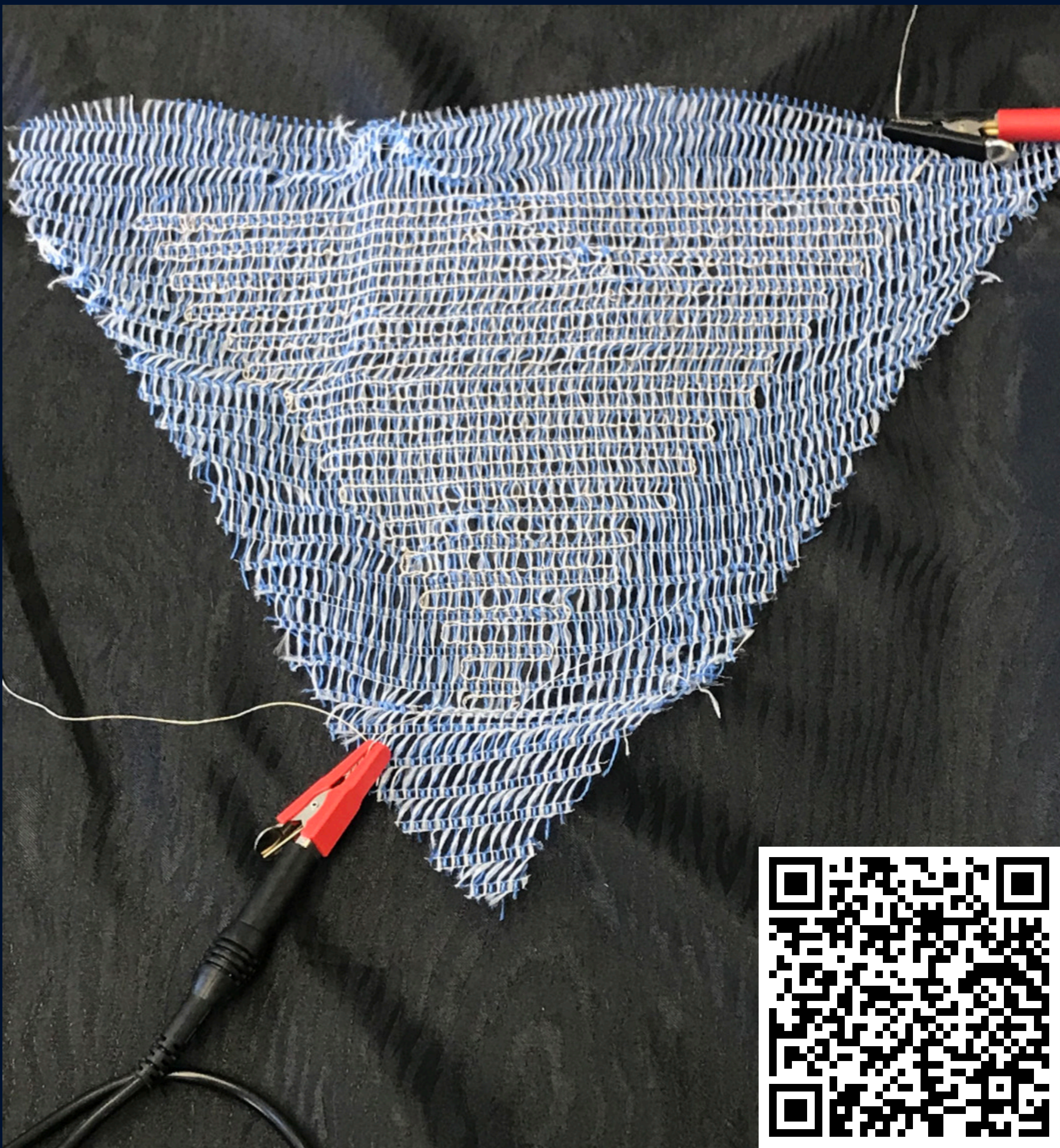


Figure. 4.14 Pemotex ribbon on bioplastic: San
(Author's

mple following the application of thermal stimuli
s archive)



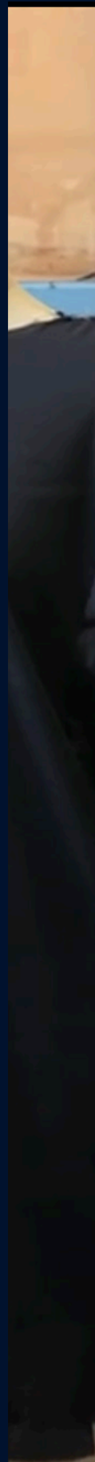


Figure. 4.15 Sleeve toile connected to power supply prior to testing.
Scan the QR code to observe the toile when power is supplied.
(Author’s archive)

Figure. 4.16 Dress demo: Changing sleeve shape to generate upper-limb awareness:
Prior to the application of thermal stimuli
(Author's archive)

Figure. 4.17 Dress demo: Changing sleeve shape to generate limb awareness:
After thermal stimuli has been applied.
(Author's archive)

4.3.3 Limitations and Considerations to Case Study II

The intuitive use of the textile provides an opportunity to work in line with everyday activities, informing body behaviours 'on-the-go' in the absence of a therapist. The textile embodies the 'hands-on' approach used by therapists (Stockley, 2020) guiding and moving the limb. The textile behaviours, however, could be more closely aligned to body behaviour (KK, 2019); i.e. by programming the response to muscle movements via EMG recordings. The degree of shrink could be controlled by the amount of Pemotex used and the garment aesthetic could be manipulated by the placement of the Pemotex; e.g. gathering or pleating (Figures A2.27 and A2.28, Appendix 2.2) adds interest and a 'fashion focus' within a 'medical device/ aid' function.

However, this does not account for the additional qualities which a 'hands on' approach with a physiotherapist contributes (see Chapter two). Additionally, further work is required to understand the parameters required to haptically navigate the limb. Since the concept was not pursued, these developments were not undertaken.

4.4 Case Study III: De-weighting the limb

4.4.1 Contextualising Case Study III

Although an individual may be informed by their movements, there exists numerous barriers towards the execution of voluntary movements. Participants noted that the limb accumulates excess weight: *"no matter how hard I try to move my arm it's just too heavy"* (AA, 2019).

Persisting non-use and muscle weakness makes supporting the weight of the limb during the execution of movement difficult. Supporting the weight of the arm is seen to reduce intrusion by flexor synergy, allowing greater ease of use by reducing reticulospinal input and enabling residual corticospinal expression (Schambra et al., 2019). Simply put, the more you control the weight at the shoulder point, the individual is seen to perform voluntary movements more easily, specifically around the elbow, but also with finger extension (Krakauer, 2018).

Current methods use haptic robots in lab and clinic based therapies; e.g., SMARTS II (Krakauer, 2018; Clinicaltrials, 2018) and for at home use, the SaeboMAS mini (Figures 4.18 to 4.23). However, accessing large pieces of equipment for a limited amount of time in clinics can limit impact. With at-home devices, limitations exist in being confined to use at a table top where the device can be clamped.

Approaches using exoskeletons in 'mobile contexts', are unpopular with participants who suggested that they would be reluctant to wear this since it would likely attract unwanted attention. Concept III considers the use of garments, as a familiar form (KL, 2019), for use in everyday scenarios.

Examples of s

a) 'Clinic

1. Haptic robots
i. SMARTS II *(Figure 4.18)*
Combining gamification with haptic robots

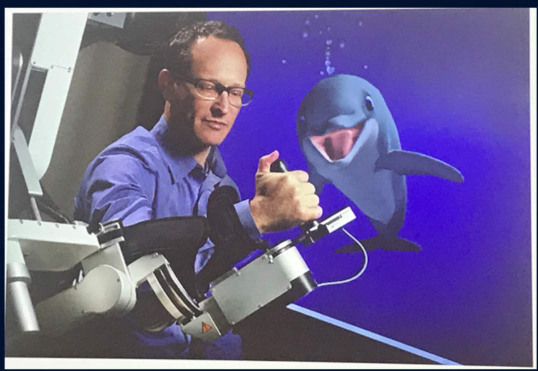


Figure 4.18 Krakauer demonstrating SMARTS II (Krakauer et al., 2020).

ii. Tyromotion Amadeo *(Figure 4.*
Robotic assisted training. Can b
used in combination with FES

Figure 4.19 Hand position in Amadeo
'device' (Tyromotion, 2020).

b) 'At-home

1. Specialist equipment
i. SaeboMAS mini *(Figure 4.22)*

Figure 4.22 Promotional photograph of SaeboMAS mini (Saebo, 2020)

similar methods

-based'

19)
e

o

2. 'Hands-on' approach

Support gained directly from the hands of the physiotherapist who uses their strength to hold and support the limb/ body *(Figure 4.21; ULP: p, 2018).*

iii. RATULS *(Figure 4.20)*
The largest study of robot-assisted arm training for stroke.

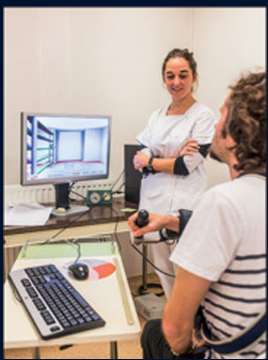


Figure 4.20 Participant with clinician during study (Rodgers et al., 2019)

Figure 4.21 Richard working with therapists (one supporting on affected side; one behind), walking frame and an inflatable splint during rehabilitation (My Amazing Brain: Richard's War, 2019)

e methods'

2. Exoskeletons
(Looned et al., 2014)

Methods may offer support by deweighting and, in some cases, assist movement but are largely still within research labs than in everyday use.

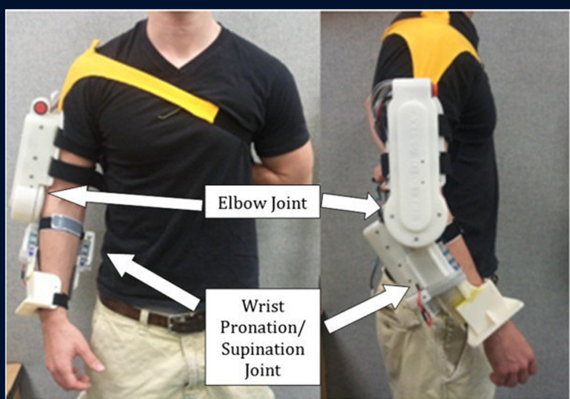
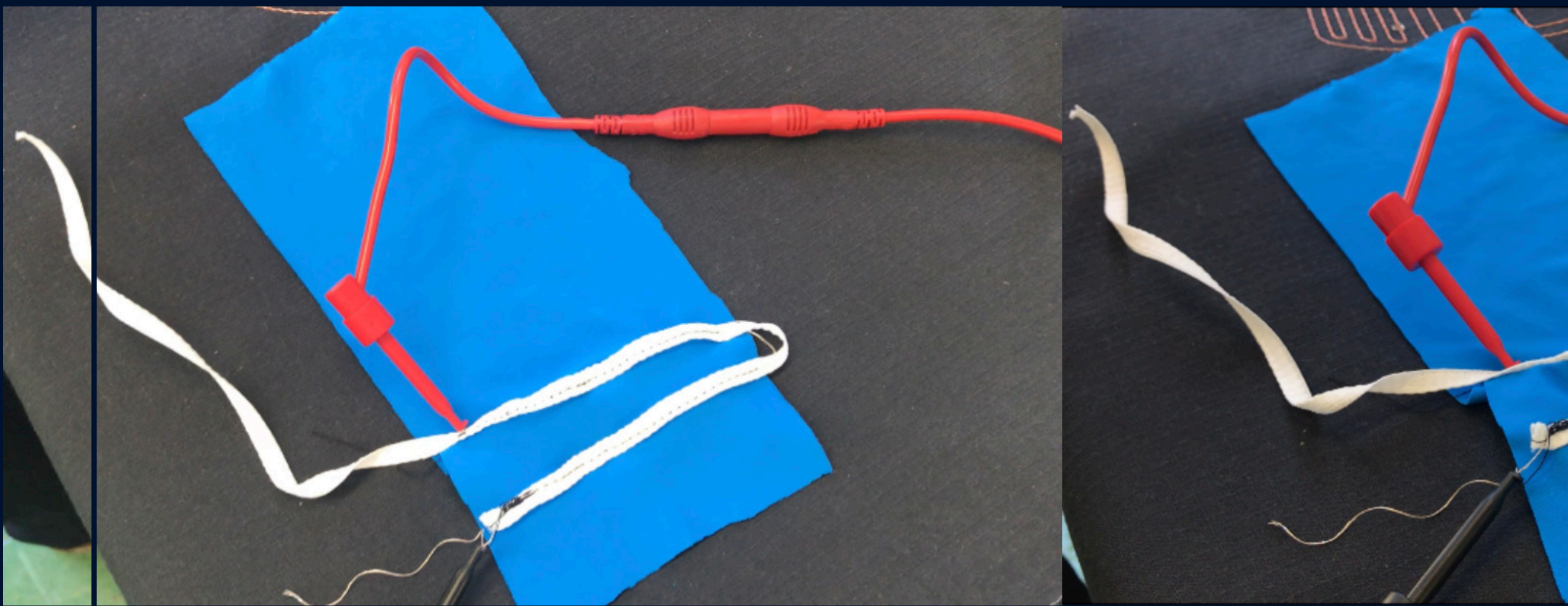


Figure 4.23 Extract from Looned et al., (2014) demonstrating participant wearing upper limb exoskeleton (ibid).

4.4.2 Method

Building on the methods used in Section 4.3, the Pemotex ribbon was utilised along with a condu
of the shape change. Further samples were constructed that integrated circuitry into the textile (Figure 4
integrated into a cotton twill (Figure 4.26) with Pemotex and cotton yarns in a manner that is indistinguis

A hairdryer was used to indicate the presence of a heat source within the concept film (Wearing Your Re



ctive yarn (Figure 4.24; Figures A2.211 and A2.212, Appendix 2.2) to control the impact and placement
.25; Figures A2.213 to A2.220, Appendix 2.2). The circuitry, created using conductive yarn, was
shable from the other yarns.

ecovery 3.0, 2018).

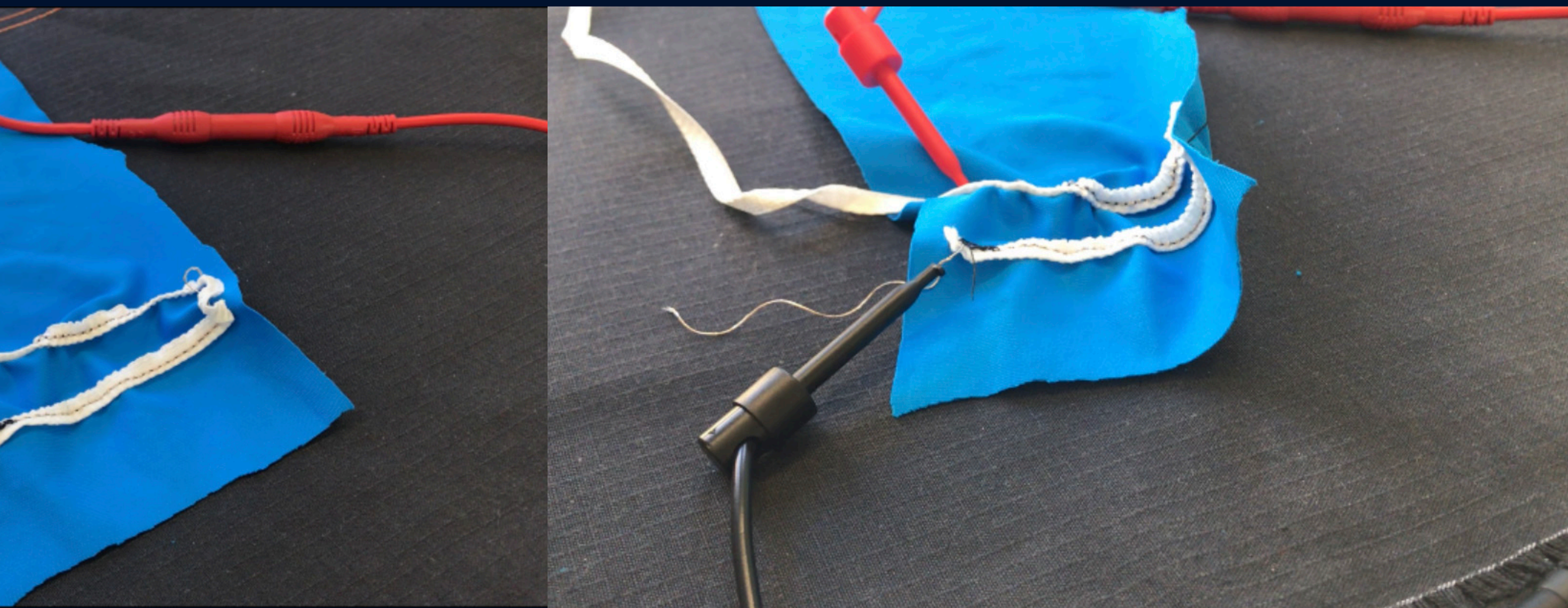


Figure. 4.24 Pemotex ribbon, conductive yarn and Lycra®: Using electrical energy to induce shape changes and counteract gravitational forces. (Author's archive)

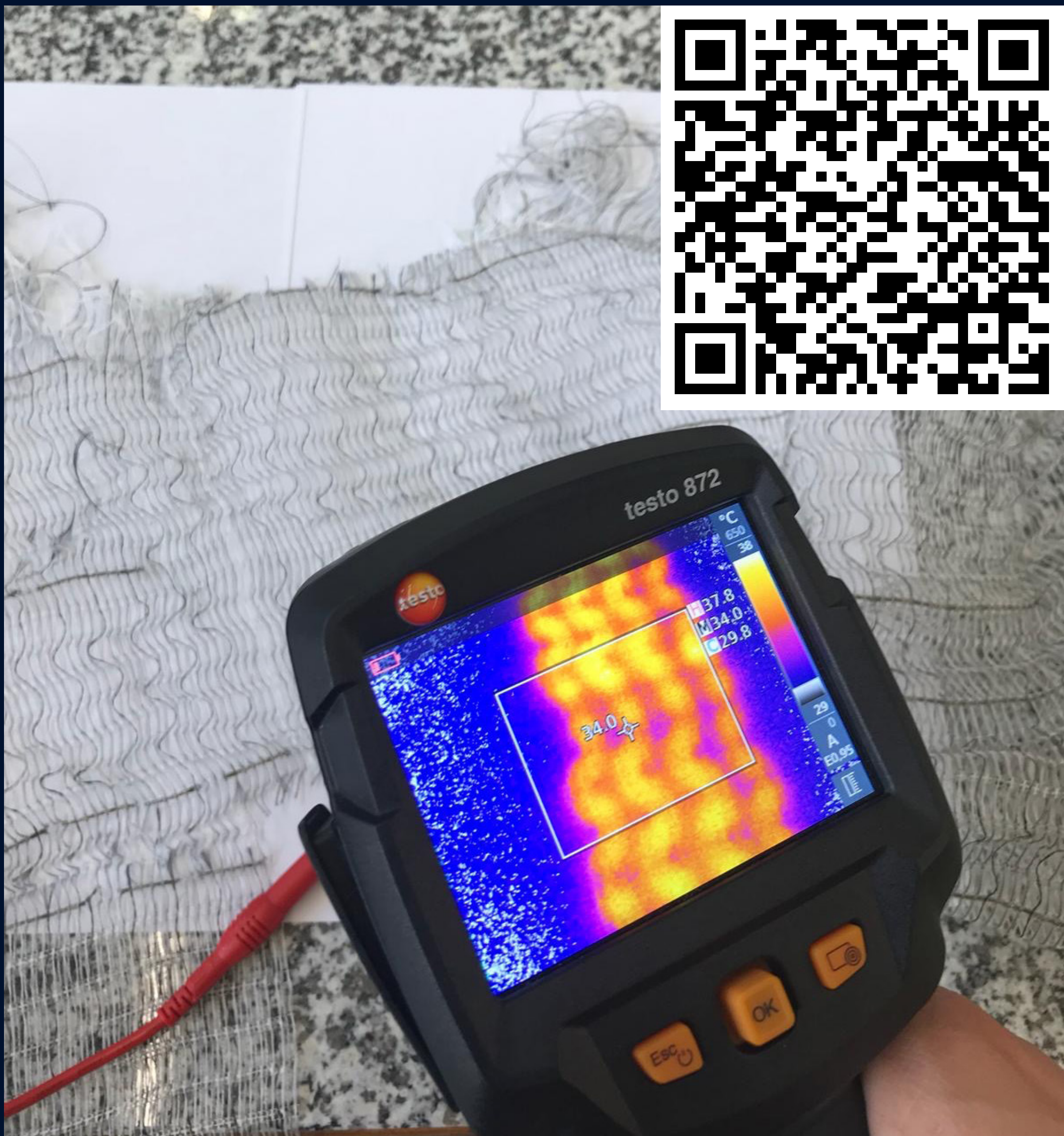


Figure. 4.25 Demonstrating thermal conduction via heat gun (Author’s archive)

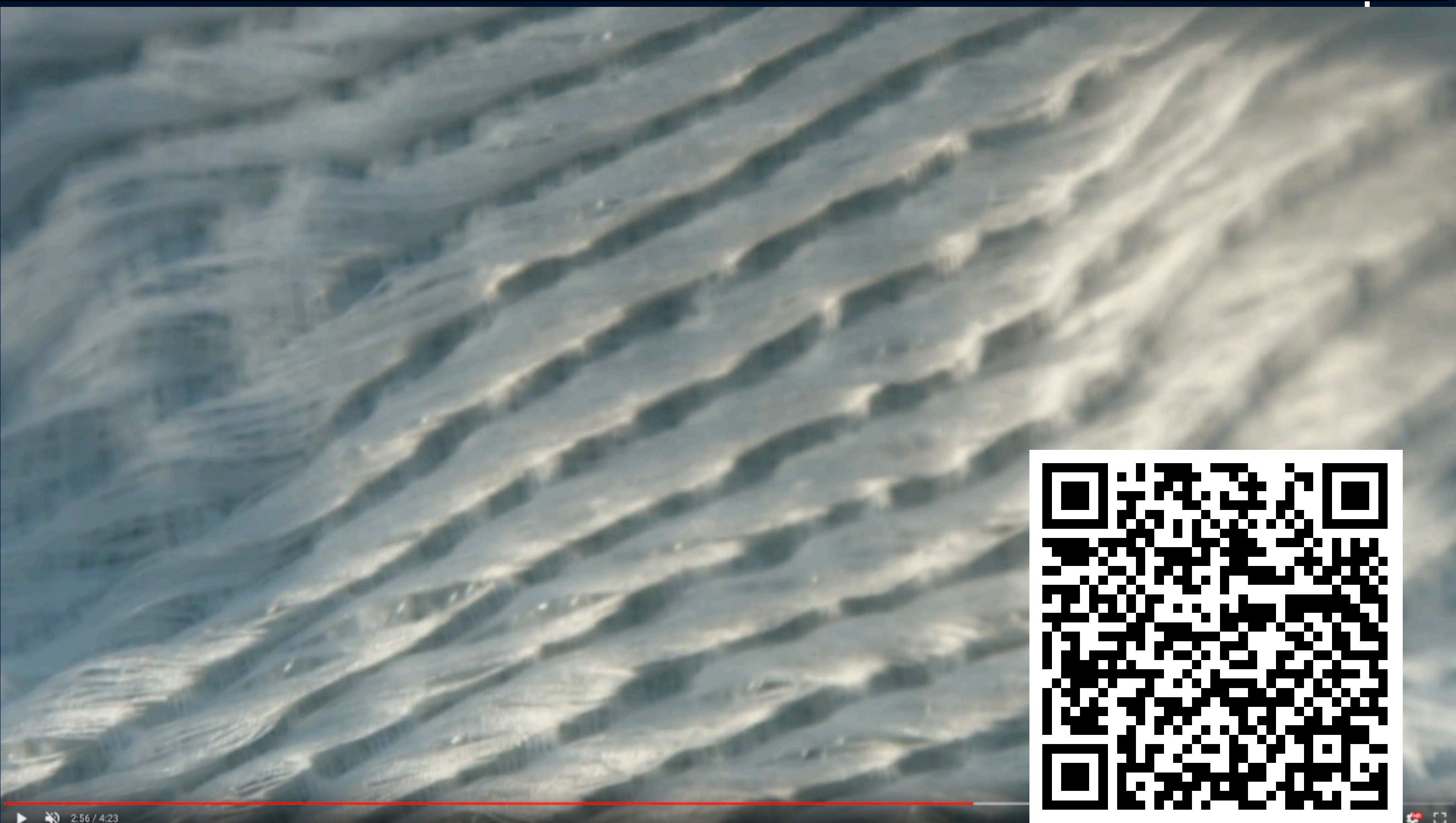


Figure. 4.26 Alleviating high forces through intelligent textiles: tested on the unaffected limb (A concept film: Wearing Your Recovery 3.0, 2018).

4.4.3 Limitations and Considerations to Case Study III

There are several limitations with this concept:

1) The levels of heat stimuli required to influence a change in the textile was too high for everyday use (within the range of 60 to 140°C). To be used effectively, this and also the use of electrical energy as the source to deliver the heat stimuli, along with the time required for the textile to respond (between two to eight seconds, depending on the temperature) requires refinement and risk assessment;

2) As we have seen in Chapter three, body temperature post stroke can be affected by injury (Tower, 1940) or medication. For some, a heated garment could have added benefits, whereas others with heighted body temperatures might be excluded from using the 'device';

3) Connections between the Inox yarns (Figure 4.25; Figures A2.213 to A2.220, Appendix 2.2) generated 'heat spots' in the textile (Figure 9.21). This may be overcome by using a continuous yarn, either via embroidery or knit techniques;

4) Increasing the number of rows of ribbon influenced the elevation of the textile from the table (Figure 4.24). However, increasing the Pemotex content would impact the handle of the textile.

Although the samples presented do not account for body weight, they provide early ideation which requires much development. It may seem possible to create 'new' muscles and 'new selves' if we refer to the work by Ray Baughman's study (Mirfakhrai et al., 2007; Haines et al., 2014) which uses a 'simple technique' of twisting and coiling high-strength polymer fishing line and sewing thread to create polymer muscles. The nylon monofilaments within the lino weave may be manipulated for this purpose. Circuitry could then be used to control the elevation of the limb within differing areas of the garment. However, monofilaments impact the handle of the textile (Chapter seven).

Furthermore, issues remain in regards to performing movements especially in the more severely impaired. Barriers including fatigue remain.

4.4.4 Chapter Summary

Findings from case studies one to three have demonstrated a range of key considerations for establishing the garment as an intervention. However, findings have also informed the type of intervention and the impact on recovery, which holds importance in determining how the features of the garment expressed in Chapter three (e.g. increasing contact with the body) can be paired with a suitable intervention.

Findings demonstrate a range of overall factors that should ideally be considered when designing an intervention, namely:

a) What are the user expectations of the treatment outcome?
Questioning how and if the performance of the intervention may live up to this, or how this may be managed through instructions, claims made and use of the intervention;

b) How quickly are results seen, or communicated to the user?
The research explores if the garment is the best tool for visualising results, and if not, what other tools are needed? This is a question for further research beyond the PhD.
c) How invaisive is the intervention?
The level of correspondence between the garment and body can be intimate. Positioning the intervention in a manner that is comfortable and an 'acceptable dialogue' between the garment and self by the individual is important. As such the research may enquire to ask, how the intervention makes the wearer feel. In case study one, the intervention was seen as restrictive and prohibitive to everyday life.
d) What user requirements are needed for the intervention to work?
It has already been established at the end of Chapter three that the garment can transgress time and space, remaining with the user throughout the day (should they stay dressed in that particular garment). However, if the intervention requires interaction with other tools, equipment or spaces, this can limit the garment's opportunity to do so. Further questions may need to be explored around this including: in what context does the intervention exist and what other tools does the intervention require in order to work? In the case of the work by Jessica Smarch (2020), this required access to a computer in order for the user to participate.

It is important to note that an intervention in a garment can impact use. As demonstrated in Chapter three (ST, pp. 125), the very presence of an intervention or aid can influence mood and behaviour towards others.
In some instances, individuals may not wish to wear the intervention at all and reside in the category of 'Rejection of Care' (Table 2.1).
However, as expressed in Section 3.2.3.2, the level of familiarity and visual aesthetic of the garment has potential to influence this.

Finally, this chapter has demonstrated that there exists many barriers to intervening in stroke rehabilitation; performing quality movements rather than compensatory techniques (case study one) and fatigue (case study three) to name but a few. It also places importance on the type of intervention on compliance of use; in how indivduals experience the feeling of the intervention when wearing it and also the benefits of the intervention. Both of these factors are seen to influence continued use (GG, 2019).

As a result, there exists a need to understand impact, both in terms of user behaviour, and their health prospects, in order to suitably propose an intervention that makes the most of the qualities of a garment.
Indeed, the potential for the garment to influence recovery holds many opportunities. In order to evaluate this further, more knowledge is required about the underlying mechanisms that contribute to upper limb function and how this might be disrupted or manipulated via the garment. As a result, the research steps back to understand what contributes to the function of the upper limb in Chapter five.

CHAPTER

5.0

Case Study Four: Manipulating neural pathway input to influence upper limb recovery through the garment

5.1 Chapter 5.0 Overview

This chapter begins by introducing the underlying neural pathways which have substantial control of upper limb function, including the limitations that occur post-stroke in recovery when the level of input from the descending neural pathways changes. The manner in which the control of these pathways can be manipulated in order to enhance recovery, and limitations of current approaches[1] are then examined.

The purpose of this is to address challenges from Chapter four that placed importance on the type of intervention, specifically the benefits to health and influence on upper limb functional recovery. Chapters six to nine will then explore the experience of the intervention that also influences adoption, integration into everyday life and continued use of the device. This includes the significance of material choice and handling of materials on delivering the intervention and user acceptance.

This Chapter therefore sets up an understanding behind upper limb function, the stimulation protocol, choice of materials to meet these parameters and theoretical calculations to support this. The concept of using the garment as a tool to intervene is developed further, analysing the materials that may be employed to deliver the stimulation.

5.2 Unpacking the underlying mechanisms that contribute to upper limb function

5.2.1 Introducing the roles of the CST and RST

The control of hand function in humans is understood to be dominated by the corticospinal tract (CST), the most developed descending pathway in humans and primates (Lemon, 2008). The CST contributes, in the most part, to finer motor control and somewhat to grip strength.

Additionally, there exists a range of other direct descending pathways (e.g. rubrospinal tract, reticulospinal tract) which act in parallel to the CST, each contributing to the control of the limb in varying ways (Riddle and Baker, 2010). The reticulospinal tract (RST) is a

[1] This is not an exhaustive evaluation of the literature, since this can be found documented within extensive reviews (e.g. Rossini et al., 2015). Rather, this section positions the reader within the context of stimulation

particularly important direct descending pathway (Riddle, Edgley and Baker, 2009; Baker, 2011) that, in contrast to the CST, contributes in the most part to grip strength, and to some degree precision grip[2] (Lawrence and Kuypers, 1968; Muir and Lemon, 1983).

Beyond its long recognised role in postural control (Prentice and Drew, 2001; Schepens and Drew, 2004, 2006), the RST also contributes to motor control throughout the upper limb (Carlsen et al., 2012; Honeycutt et al., 2013; Dean and Baker, 2017). Although overlooked in the most part within literature, the RST holds strong contention for *"the neural substrate of strength training[3]"* (Glover and Baker, 2020). Notably, strength training[4] is considered to be influenced more so by neural adaptations in the RST, than the CST (ibid). This 'shared control of the hand' means that, when injury occurs, incurring damage to the CST, another (for example, the RST) can take over.

[2] During power grip, little to no cell action firing was observed when recording cortico neuron firing in the cortex from the CST. Whilst, during finer dextroust tasks, significant cell action firing was noted, suggesting that there may be multiple ways in which the hand is used; pathways of which do not originate in the cortex, but that hold connections to one another (Muir and Lemon, 1983). These are observed via direct or indirect connections by both projecting to motorneurons innervating both distal and proximal muscles (Davidson and Buford, 2004, 2006; Riddle et al., 2009) or spinal cord interneurons (point a. on Figure 5.1); many of which are shared between the CST and RST pathways (Baker, 2018).

[3] As a result of the manner in which the RST can influence the body bilaterally (Jankowska et al., 2003; Schepens and Drew, 2006; Davidson et al., 2007) in combination with the synergies that result from its high degree of convergence (Peterson et al., 1975; Matsuyama et al., 1997; Zaaimi et al., 2018a).

[4] The initial stages of which are seen to be dominated by "neural adaptations rather than intra- muscular mechanisms" (Moritani and deVries, 1979; Sale, 1988; Folland and Williams, 2007).

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Figure. 5.1 A diagrammatic representation of stimuli location in reference to the internal neural pathways (Adapted from Baker, 2018; Author's archive).

5.2.2 The CST and RST post stroke

Following a corticospinal lesion as a result of stroke or brain injury, levels of input from the CST and RST to the upper limb and hand changes. Within the first six weeks post injury, natural biological recovery occurs (Krakauer, 2018) where neuronal plastic changes are observed (Balakrishnan and Ward, 2013). Damage incurred reduces levels of CST input, the level to which is in the most part determined by the extent of injury. To compensate for this loss the RST is seen to increase input to the upper limb, partly subserving recovery (Zaaimi et al. 2012).

As a result of increased RST input, the flexor muscles (Figure 5.2) become selectively strengthened whilst extensor muscles (Figure 5.2) remain weak (Baker, 2011). However, the rise in input from the RST can limit the quality of recovered movements (Baker et al., 2015; McPherson et al., 2018), presenting a barrier to engaging in upper limb training[5]. This can be exacerbated with prolonged non-use which can lead to contracture, enhanced pain, further impacting the use of the limb and the physical identity and behaviour of the body.

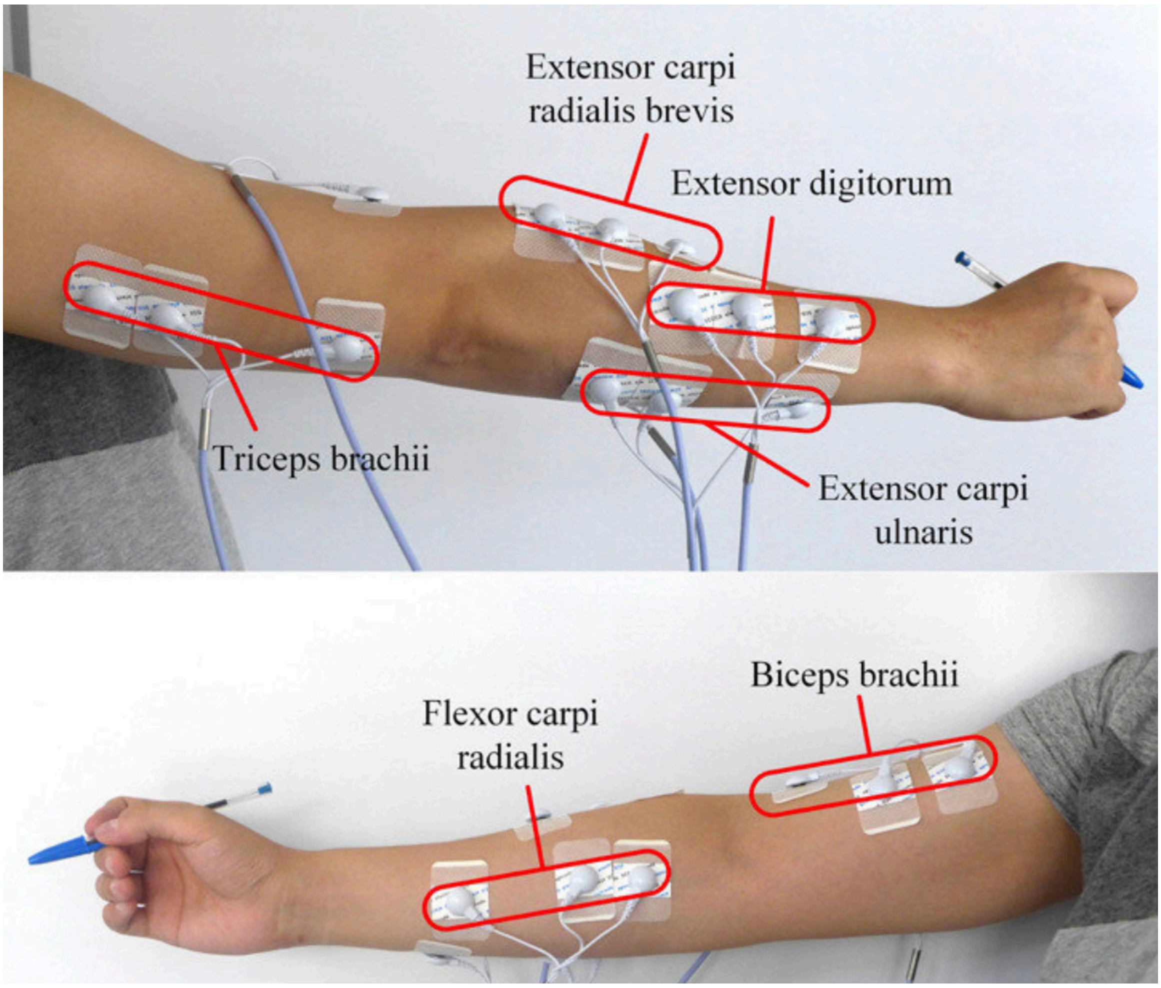

Figure. 5.2 Visualising the positioning of flexor and extensor muscles; Indicated by electrode placement (Yang and Chen, 2016).

[5] A permanently closed hand, with little to no grasp rendering the limb 'functionally useless' (Twitchell, 1951).

The restoration of strength in the extensor muscles is a common and important aim of rehabilitation (Cauraugh et al., 2000). Regulating or modifying the level of input of the RST is suggested to improve the functional output of the upper limb, specifically, by targeting intrinsic hand muscles, forearm flexors and extensors (Baker and Perez, 2017; Choudhury et al., 2020).

Manipulating the RST 5.3

5.3.1 Introducing the approach

Studies led by Baker (Riddle et al., 2009; Riddle and Baker, 2010) suggest that it is possible to activate and modify neural pathways using external stimuli[6]; e.g. via TMS (Ziemann et al., 1999; Fisher, et al., 2012) and via FES paired with a loud 'click' (Foysal et al., 2016; Choudhury et al., 2020). Non-invasive peripheral nerve stimulation can also be used to enhance strength training[7]. Additionally, pairing stimulation with adjuvant techniques such as voluntary contractions of the muscles during ADLs for example, can enhance restorative approaches[8] (Carson and Buick, 2019).

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[6] "The processing of sensory inputs and commands to motor neurons and muscles is distributed in hierarchically interconnected areas of the spinal cord, brain-stem and forebrain. [...] Sensory information relating to movement is processed in different systems operating in parallel" (Ghez and Krakauer, 2006).
[7] Stimulation was delivered via implanted electrodes in the pyramidal tract (PT), medial longitudinal fasciculus (MLF), bilateral medial and lateral M1 in the study by Glover and Baker (2020).
[8] The "efficacy of [...] exciting corticomotor output may be increased [when using TMS] by asking the patient/subject to pre activate the target muscle at 10-20% of maximum strength" (Rossini et al., 2015).

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Figure. 5.3 The ‘click and shock’ approach (Baker, 2018; Foysal et al., 2016).

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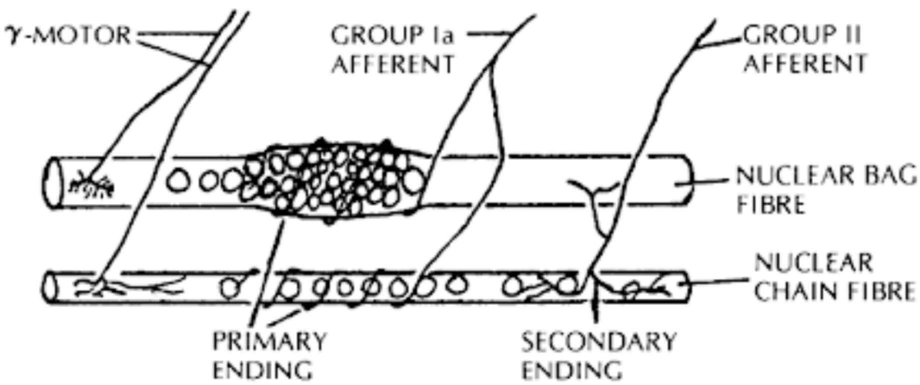

Figure. 5.4 Image contextualising the muscle spindle Ia afferents in a “diagram of the two intrafusal muscle fibre types and their innervation”. (Adapted by Fitz-Ritson, 1982 from Matthews, 1964).

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5.3.2 Evaluating approaches to stimulation

The practice of using electrical stimulation on man dates back to around 2400BCE (Finger and Piccolino, 2011) with artificial muscle stimulation being described to varying levels in texts from Largus (Cambiaghi and Sconocchia, 2018) and Dioscorides (Gunther, 1934; Kellaway, 1946); and later on by Franklin's observations of muscle contraction via static electricity (Isaacson, 2003). The controlled delivery of current to the body by Faraday's application of magnetic induction (Carson and Buick, 2019) extends this body of knowledge.

After an extensive history of use within medicine the use of electrical stimulation methods in clinical practice, particularly within stroke rehabilitation, are still questioned; in terms of being fit for purpose[12] (Bestmann and Ward, 2017) and clinical effectiveness (Krakauer, 2018).

In addition to the social considerations of such devices (Section 1.2, Chapter one; Section 3.3, Chapter three), and positioning the electrodes are a further barrier to use. Studies have increasingly sought to integrate pre-positioned electrodes within garments (Finni et al., 2007) and sleeves (Sharma et al., 2018) to overcome this. Yang et al. (2018) suggest a method of incorporating FES into a sleeve as an effective way of recovering movement post-stroke (Veerbeek et al., 2014; Popovic et al., 2014; Howlett et al., 2015), albeit not considering the level of impact from adaptive and restorative perspectives (Carson and Buick, 2019), but noting the difficulties in self-administering it; particularly with positioning the electrodes on the body. They suggest countering the issue by constructing an array of pre-positioned screen printed electrodes in the sleeve (Figure 5.5) which can be individually controlled.

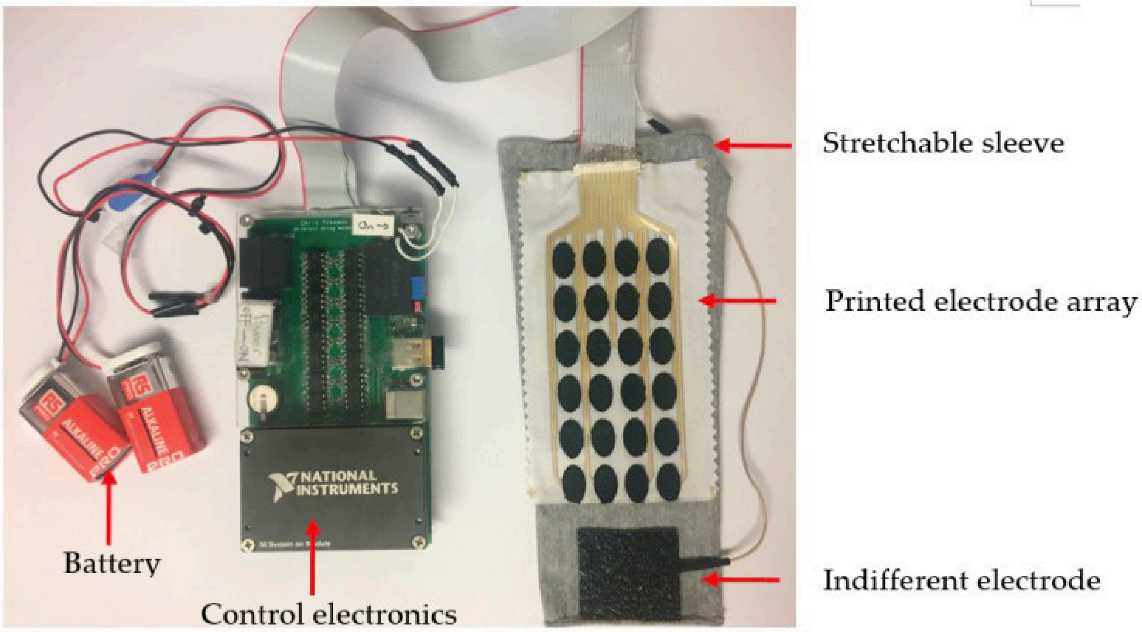

Figure. 5.5 E-textile FES sleeve. (Yang et al., 2018).

[12] Dose control is important since the 'effective dose' of stimulation methods is 'highly variable across individuals' (Bestmann and Ward, 2017).

Methods of electrical stimulation face many further challenges, particularly with traditional adhesive gel electrodes including general irritation from materials used to construct the electrodes. As a result, individuals may pursue implanted devices where absolutely necessary or go without. Traditional gel electrodes have to be regularly replaced since their performance reduces over time as a result of moisture evaporation and faster contamination build-up (Yang et al., 2018). The development of dry electrodes may solve this issue, but in doing so raise further issues of discomfort caused by the high impedance between the dry electrode and skin (Zhou et al., 2015; Stewart et al., 2017).

5.3.3 Reconsidering the approach

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5.3.4 Context: The use of mechanical stimulation in textiles and garments

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Stimulation Protocol Hypothesis & Component Analysis

5.4

5.4.1 Stimulation Protocol Hypothesis

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Table 5.6: Stimulation protocol hypothesis

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It is hypothesised that muscle spindle activation may be achieved within the range of the following parameters noted in Table 5.7 (Salisbury and Baker, n.d):

Table 5.7: Overview of criteria required to elicit a muscle spindle response

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To achieve this, a range of off-the-shelf components have been theoretically evaluated; pneumatic actuators, solenoids, voice coils and piezoelectric actuators. An evaluation of their ability to meet the functional requirements of the stimulation protocol as well as their assessment in line with findings from participatory design sessions (Chapters two and three) have been included.

5.4.2 Component Analysis

5.4.2.1 Pneumatic Actuators

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Figure. 5.8 Example pneumatic actuator (Haptx 'microfluidic skin')

Table 5.9: Theoretical assumptions of use of pneumatic actuators

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[The following text that appeared in the thesis was redacted due to its commercially sensitive nature.
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5.4.2.2 Solenoids and Voice Coils

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Table 5.10: Theoretical comparison of solenoids to voice coils

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5.4.2.3 Piezoelectric Actuator

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Table 5.11: Theoretical comparison of piezoelectric actuators

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[The following text that appeared in the thesis was redacted due to its commercially sensitive nature.
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Developing e-textile components is not solely about meeting performance needs, albeit an important role, but consideration must also be given to how the added function impacts the relationship between garment and wearer and how this can be manipulated.
The following chapter (six) will therefore explore the potential for manipulating piezo materials for use in powering and acting as a mechanical stimulus in the garment whilst remaining critical of the challenges for doing so.

Figure. 5.12 Coin cell and ‘pocket’ (Beeby and Torah, 2020)

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CHAPTER 6.0

Technical analysis: Exploring the application of piezoelectric materials to textiles

6.1 Chapter 6.0 Overview

In Chapter five, the opportunity for utilising piezoelectric theory[1] to activate the muscle spindle Ia afferents (MSAs) and manipulate RST input was introduced, demonstrating the potential to power the device and, with further experimentation, possibly delivering the stimulation protocol. Notably, the use of energy harvesting methods presents an opportunity to re-think a typically passive role of the wearer of a wearable medical device, to a more active one. However, the implementation of this requires much consideration, including:

i) how the choice and synthesis of material elements may influence the efficiency, feasibility and form of the device, affecting levels of 'wearability';
ii) whether a desirable force can be achieved in order to influence the MSAs;
iii) if the textile can deliver enough energy to power the device;
iv) the most suitable form which the 'device' will take.

Chapter six will explore the practicalities of using piezoelectric materials, beginning by providing a context to using piezoelectric materials within textiles (Sections 6.2 and 6.3), leading onto key considerations for delivering the intended stimulation protocol and a 'working hypothesis' (Section 6.4) through a literature review. Chapters seven and eight will build on this through further within research practice.

Exploring the theory of piezoelectricity 6.2

6.2.1 Introducing piezoelectricity

The piezoelectric effect refers to the ability of some materials to acquire an electric charge on the application of mechanical stress. When a mechanical stress is applied to a piezoelectric material, the crystal structure of that material is caused to polarise, resulting in a charge developing between opposing sides of the material, generating current. Piezoelectricity is not a linear process but a reversible one. An imposed voltage produces mechanical deformation/strains the material (Figure 6.1).

[1] Where the chapter evaluates energy harvesting principles, specifically the "amount of charge generation is proportional to the amount of stress placed upon the material [and vice versa]" (Dirjish, 2012). Therefore, the optimisation of the piezo material to harvest energy is simultaneously considered to optimise the inverse piezo effect required for stimuli generation.

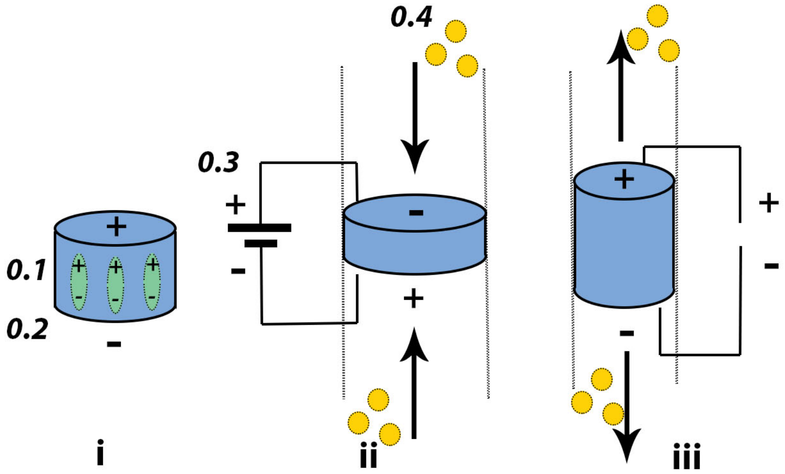


Figure. 6.1 Visualising the material's dimension when similar and opposing poling voltage is applied (adapted from Dahiya and Valle, 2013)

i - original state/ no application of voltage;
ii - reverse polarisation through the application of voltage;
iii - direct polarisation
0.1 - graphical display of orientation of dipoles in PVDF
0.2 - piezoelectric material
0.3 - power supply
0.4 - external particles

In the year following the discovery of the piezoelectric effect in 1880 by the Curie brothers (Curie and Curie, 1880), Lippmann (1881) predicted this converse effect known as the 'inverse piezoelectric effect'. Piezoelectric materials are operable to deform when an electric current is applied to such a material.

The inverse piezoelectric effect causes oscillations in the crystal, controlled by the electrical input. As the applied voltage increases, the force and displacement increase (Aerotech, 2019). An example of this process can be seen in Figure 6.2.

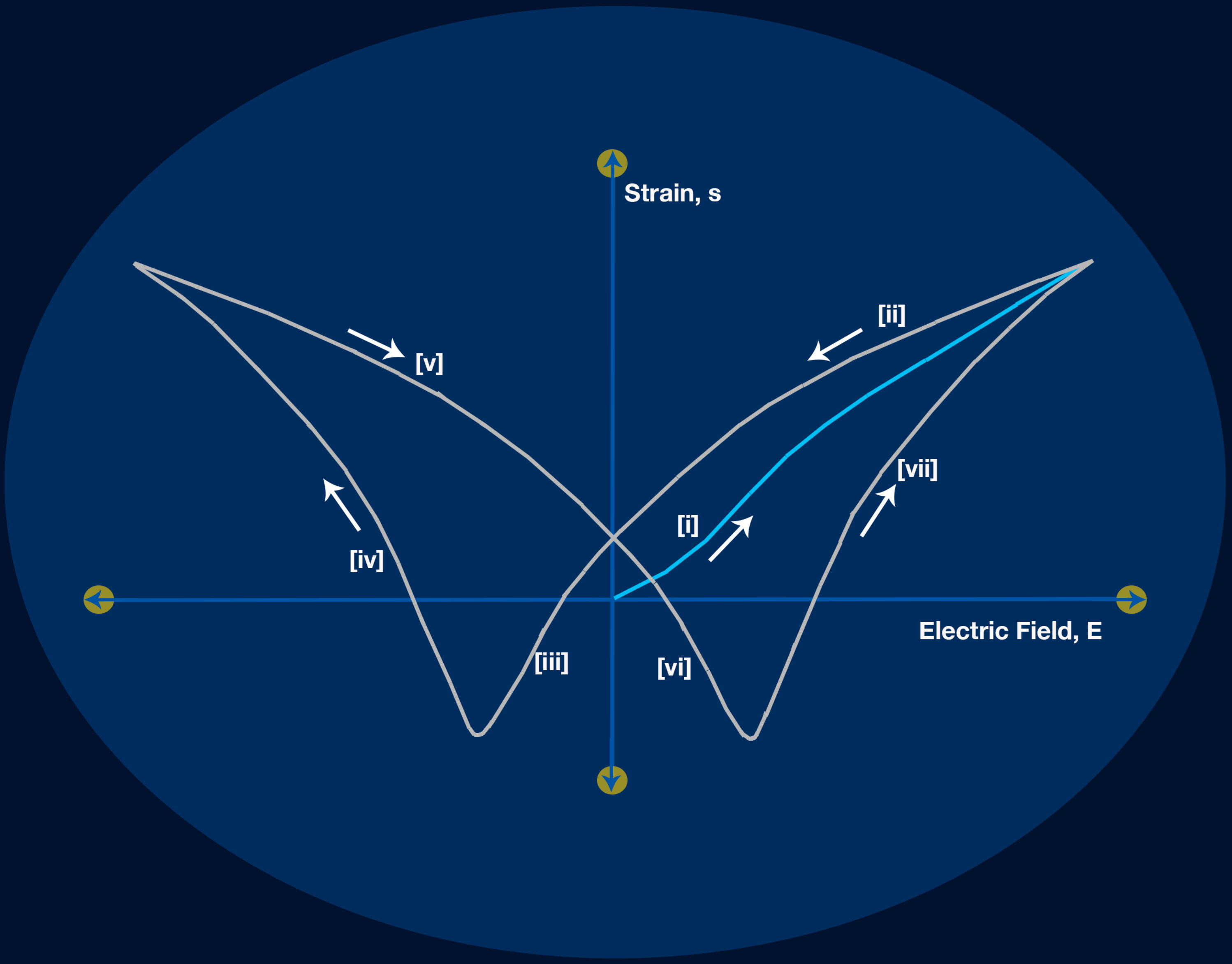


Figure. 6.2 An example of displacement behaviour in the inverse piezoelectric effect (Adapted from Aerotech 2019)

Immediately after the electric field is applied, strain increases **[i]** and the dipoles align (as closely as possible) in the direction of the electric field.
The strain decreases (typically more slowly than [i]) when the direction of the electric field is reversed **[ii]**, increasing in rate as the dipoles orientate back to their original position.
The dipoles become reorientated in the opposite direction as the material becomes polarized due to the increasing negative electric field **[iii]**.
The piezo material begins to expand again **[iv]**.
Upon reaching its physical strain limit, the electric field is reversed causing the strain to decrease **[v]** as the dipoles revert back to their original position.
When reaching the coercive limit **[vi]**, the dipoles are again polarized and the piezo material expands to its physical strain limit as the electric field is increased **[vii]**.

6.2.2 Influence of beta phase fraction

Piezoelectric performance is highly dependent on the beta phase [β] fraction (Jain et al., 2015). In PVDF, for example, the orientation of the dipoles in beta phase is linear unlike in the other three phases (alpha [α], gama [γ] or delta [δ]) which are randomly oriented (Figure 6.3). As a result, beta phase *"exhibits spontaneous polarisation, and thus piezoelectricity"* (ibid: 1589). This linear orientation separates surface charge to opposing positions in the piezo material (Figure 6.4). The application of a compressive or tensile force to the material leads to a decrease in polarisation, altering the direction of the dipoles. Upon the release of the force, the dipoles return to their linear position. An electrical output is generated as a result of consistent cyclic application and release of a compressive or tensile force.

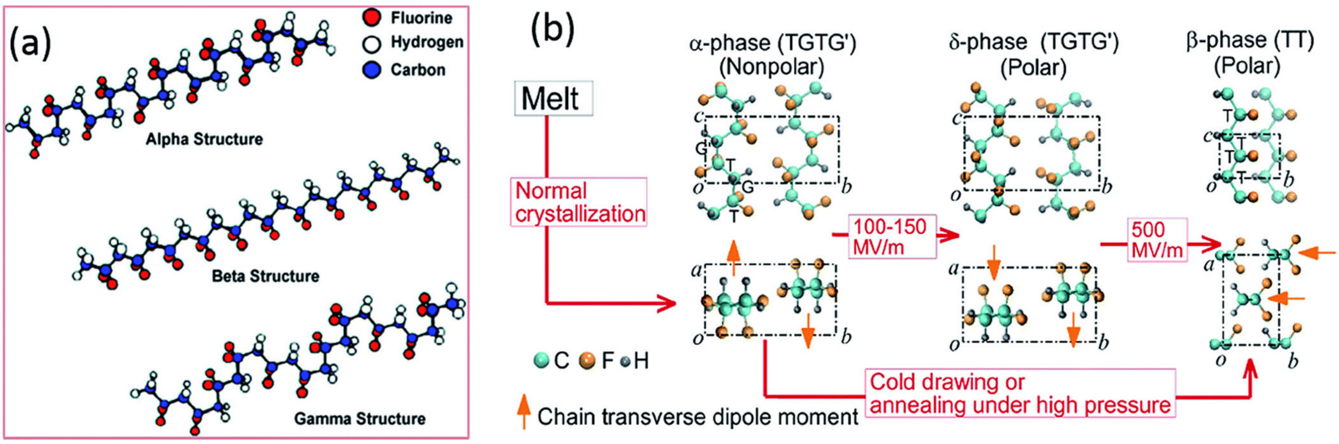


Figure. 6.3
(a) - Graphical representation of the alpha, beta and gamma polymorphic crystalline phases of PVDF (Ameduri, 2009)
(b) - Visualising the electrical field-induced phase transitions of PVDF (Yu and McGaughey, 2016)

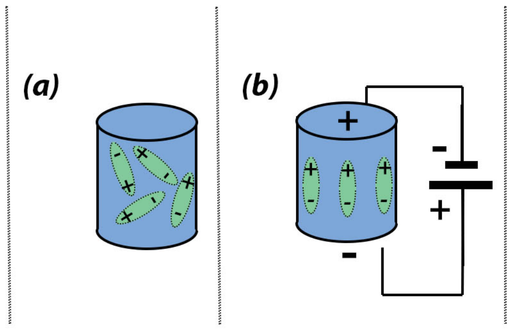


Figure. 6.4 Visualising the piezoelectric effect under polling conditions
(a) - Original state with random arrangement of domains;
(b) - Whilst undergoing poling, the domains align
(adapted from Dahiya and Valle, 2013)

Enhancing β-phase of PVDF can be achieved by the use of fillers (Appendix 2.3) or via copolymerisation (e.g. vinylidene fluoride; trifluoroethylene; chlorotrifluoroethylene; hexafluoropropylene)[2].

Detecting the presence and calculating the amount of beta phase within specimens via DSC and XRD analysis respectively provides an indication to the level of output performance. Section 8.4 (Chapter eight) details DSC analysis of initial specimens.

The manner of transforming the electrical electric energy into usable mechanical energy by piezoelectricity is fundamental to the applications such as nano-positioning devices (Dahiya and Valle 2013), displacing a coupled mechanical load and has been used in the development of actuators. It is in the area of actuators that this research is most concerned with; for creating a textile-based mechanical stimuli component (Section 6.4).

6.3 Considerations for using piezoelectric methods in a 'wearable' context

The application of piezo materials to wearable contexts presents many challenges that influence the compatibility with the expected handle of textile-based materials; e.g. flexibility, breathability and stretch (Chapter seven). Ever since the discovery of piezoelectricity in PVDF in 1969 (Kawai, 1969), various polymer structures have been investigated and utilised in many applications that seek to overcome compatibility issues. Although the piezoelectric properties of PVDF are regularly highlighted as being much poorer than that of ceramic-based materials (e.g. PZT and $BaTiO_3$), the flexible properties of polymer materials makes them an attractive option for use in sensor and actuator applications (Hadimani et al., 2014).

The brittle nature of inorganic ceramics and their capacity to work at small strain levels (~1%) is seen to restrict their application to larger scale textile-based contexts (Zeng et al., 2013; Fang et al., 2013; Chen et al., 2017).

The presence of lead in ceramic-based materials such as barium titanate and lead zirconate titanate prevent them from being suited for use in wearable health devices (Soin et al., 2014). Lead-free inorganic ceramics, e.g. $BaTiO_3$ (Yaqoob et al., 2017) overcome this issue, whilst alternative materials such as PVDF present non-toxic, flexible, lightweight, biocompatible and electroactive opportunities (Huang et al., 2010; Lin et al., 2012; Saravanakumar et al., 2013; Park et al., 2013; Alam et al., 2015; Karan et al., 2015). Having said this, ceramic-based components can be manipulated to increase their flexibility, weight and behaviour, to a limited extent, via additional processes (Almusallam et al., 2017; Chou et al., 2018).

[2] The alignment of the polymer chains in an "extended planar zigzag all-trans conformation" is facilitated by the presence of a co-monomer unit - specifically when the TrFE content is over 11 mol% (Oliveira et al., 2014). When this reaches 20 mol% or above, the "formation of β-phase is independent of the processing conditions and electric poling" (Hu et al., 2009) which can be beneficial since the effects of poling can be limited.

Material choice for applications may vary, depending on their context of use, yet, the following criteria demonstrates key considerations for wearable devices to attend to: *"(i) be imperceptible to the user; (ii) not load the user; (iii) provide long term lifetime with reasonable power densities (dependent on the application); and (iv) be cost-effective and inexpensive to produce"* (Mitcheson et al., 2008 in Soin et al., 2014: 4)

Within the literature, examples centre around four common approaches:

1) Creating new 'flexible' composite materials

(Non-woven: Rubbery Matrices); e.g. by depositing ceramic nanofillers which exhibit high piezoelectric coefficients (e.g. PZT: Chou et al., 2018) into polymer matrices (Parangusan et al., 2017; Ponnamma et al., 2018).

2) Applying energy harvesting materials to a textile substrate

(Non-woven: Films); e.g. in the form of screen printing (Almusallam et al., 2017) or thin films.

3) Combining individual yarns (Textile: combining multiple yarns) to either: form electrode, piezoelectric and insulation layers (Kwak et al., 2017); or integrate opposingly charged yarns to form triboelectric nanogenerators (Zhang et al., 2015c).

4) Creating new yarns (Yarn: PENG/TENG formed into a single yarn) by: combining layers of functional materials, integrating electrodes etc. (Raj et al., 2018); twisting or braiding yarns together (Yu et al., 2017); spinning new fibres (Park et al., 2019) or impregnating existing yarns, e.g. cotton, with nanomaterials (Mirvakili et al., 2015).

A summary evaluation of these four areas is provided below (Table 6.5), whilst Table A2.41 in Appendices 2.4 provides a summary of the output performances of key literature. Measurements and key values provide guidance for the design of the device which follow in subsequent chapters.

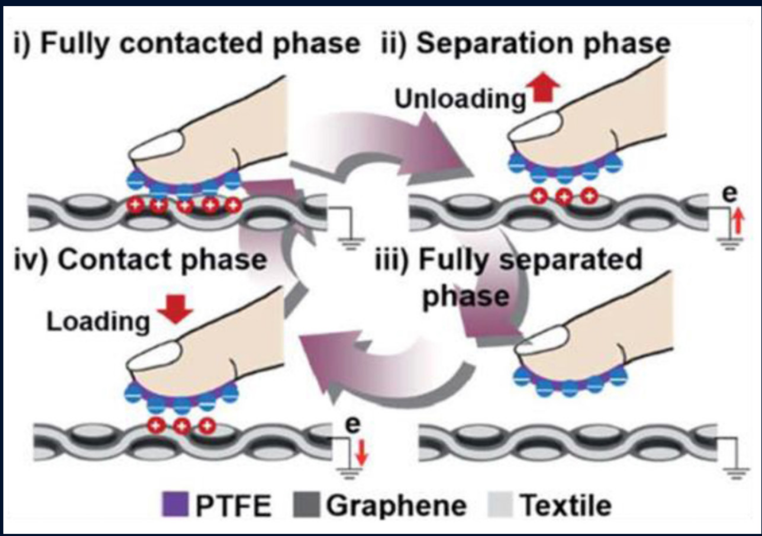
Table 6.5: An evaluation of material specimens within key literature

Approach	Key Insights
Non-woven: Rubbery matrices	1) Although the 'SPENG' [stretchable piezoelectric nanogenerator] by Chou et al. (2018) displays a higher degree of flexibility, the resulting rubbery matrices are seen to be incompatible with the behaviour of 'familiar/ traditional' textiles; having differing material qualities in flexibility, thickness, etc. 2) Since the electrode layers benefit from reportedly remarkable abrasion and tear resistance qualities, this approach is suited to being subjected to greater levels of abrasion etc. during wear, and therefore at particular locations in a wearable; e.g. the soles of shoes (Almusallam et al., 2013). 3) Lower amounts of ceramic filler can reduce energy harvesting properties of the composite due to the positive and negative piezoelectric coefficients becoming cancelled out Yaqoob et al., (2017). However, greater amounts can reduce overall mechanical flexibility. 4) Using a polymer of the same chemical structure for the matrix as the fillers significantly improves the dispersion of fillers and enhances the dielectric properties (Qiao et al., 2014). The seamless connection created as a result, improves the contact area (Chou et al., 2018). However, the use of polymers can limit the stress/strain exhibited on the ceramic fibres, reducing their overall performance. 5) Jung et al. (2015) demonstrates the shape of the material plays a key role in optimising power generation. A curved structure is deemed advantageous in that it distributes the *"applied force across the piezoelectric layer"* (Jung et al., 2015: 174) whilst enabling it to operate at a *"lower frequency vibration range"* (ibid). This data may be taken into account for the shape and material composition of the bead casing in 'Hypothesis 2.0' (Section 6.4).
Non-woven: Films	1) Screen printing is a method that is well-suited to mass production of piezoelectric devices. Printing can be achieved on large scales (limited by the equipment) in pre/post production processes of garment construction. 2) Single layer piezoelectric materials can be printed in vast quantities and in various patterns. The use of screen printing can be used to intelligently embed functional energy harvesting material properties into logos, prints and graphics on garments to compliment body image and identity; or hidden and placed on the inside of garments. 3) In some cases, the textile proves to be a challenge for application of energy harvesting materials via lamination or coating processes due to its *"rough, inconsistent surface profile"* (Torah et al., 2018), resulting in poor interface bonding between the piezo material and electrode. 4) Applying an interface layer (Almusallam et al., 2017) reduces the surface roughness and negates any surface pilosity (protruding fibres) that would otherwise prevent the printing of consistent working samples (Yang et al., 2018; Yang et al., 2013). 5) Investigations in Chapter eight include samples with electrospun PVDF films to test participant responses to this method, albeit via similar yet not exact methods to the literature.

Approach	Key Insights
Non-woven: Films *[continued]*	6) The positioning and scale of the printing of triboelectric materials requires consideration. Similarly to piezo materials the triboelectric response also requires cyclic patterns, this time in terms of contact and separation between the oppositely charged materials. In examples using triboelectricity, Paosangthong et al. (2019) demonstrate placement of the TENG on the sleeve (close to the cuff) and on the hips, perpendicular to the sleeve suggesting that the contact between the two layers can generate output voltage during walking and running as a result of the swinging of the arm. 7) An understanding of the key behaviours that exist during wear is important here since this requires a significant level of contact between the limb and the hip area, which may limit efficiency and use (Mitcheson et al., 2008). 8) Alternative approaches may include knitting (or weaving) patterns within the textile (Figure 6.6) to increase contact areas; even moving beyond simple stripes as shown in the study to patterns that consider optimising the output performance and visual aesthetic/ desirability of the garment as well.
Textile: multiple yarns form textile-based PENG/ TENG	1) This method is highly dependent upon the textile structure (Kwak et al., 2017) and yarn type[3]. In comparison to single or double bed structures, the numerous layers required to create a spacer increases the textile's overall thickness that it becomes limited for use amongst more seasonal, warmer garments. 2) Studies investigating knitted single-structure PENGs (Soin et al., 2014) and TENGs (Liu et al., 2016) note that spacer structures are particularly suited to energy harvesting contexts by optimising the conditions for enhancing compressive forces. The effectiveness of the spacer structure is dependent on the integrity of the structure to separate the surfaces and position yarns to adequately insulate and separate the electrodes, avoiding short circuiting the component. 3) The characteristics of the yarn creating the spacer structure will determine the rate of 'recovery' from deformation and the level of separation; i.e. stiffer yarns that are melt spun for example as in Soin et al. (2014), would retain a more perpendicular positioning to the surfaces of the textile than yarns with a less rigid property. This will also influence the handle and behaviour of the textile on the body, determining the garment type and body image. The stretch exhibited by the spacer structure, influencing output performance (Kwak et al., 2017) which is in turn affected by garment fit, depends on the properties of the yarns used, tension and textile structure (explored in Chapter seven). 4) In other examples, (Chung et al., 2018) the body becomes utilised as an active material (acting as an electrode) contributing towards the generation of output power. The limitation here is in the application of PTFE to the body (Figure 6.7) which may be intelligently constructed into two complimentary garments. An understanding of the use of layering and behaviours that exist in wearing garments is necessary to create a user-friendly approach to this method. 5) Unlike Chung et al. (2018), Lai et al. (2017) develops an approach which requires just one textile layer, utilising direct contact with the skin. However, issues regarding this contact including chafing, comfort (typical degrees of softness experienced with a garment) and skin irritations are not considered.

Approach	Key Insights
Yarn: PENG/TENG formed into a single yarn	1) Yarn-based methods are easily integrated into existing textile industry manufacturing methods and are noted for the ability to provide piezoelectric output under highly variable mechanical deformation, high fatigue resistance and low levels of strain. 2) Where piezoelectric films are often restricted to size based on production model/ machinery etc. a piezoelectric fibre can be woven or knit into larger scales of fabric (Hadimani et al., 2014). 3) Rather than combining several different yarns with differing material properties together, a single yarn may contain layers of various functional materials (Raj et al., 2018). 4) The ordering of the layers is important, as is ensuring the separation of electrodes. In Raj et al., (2018) the PVDF layer simultaneously acts as the piezoelectrically active material, as a 'blocking layer (insulator) for sudden charge transportation'[4] and improves the flexibility of BiTO nanoparticles (NPs). 5) The diameter of the yarn can limit integration into textile manufacturing processes (Wang et al., 2016; Tian et al., 2018). 6) 'Multi-material' and 'multi-process' methods used to construct a more compact yarn (Egusa et al., 2010) from P(VDF-TrFE) resulted in a more expensive fibre that is difficult to scale up in production. Melt spinning[5] on the other hand is a continuous process that is less time consuming and less expensive (Hadimani et al., 2014; Soin et al., 2014). 7) In unpoled melt extruded samples, β phases were observed, which may be due to the high temperatures and tensile stresses exerted on the PVDF (Hadimani et al., 2014). However, this was lower than that of poled samples. The poled samples exhibited superior mechanical properties than unpoled films, arguably due to the 'morphological organisation of the ferroelectric polymer'. This has also been observed in similar studies (Sencadas et al., 2003; Gomes et al., 2010). 8) Yarns produced via electrospinning do not require additional poling since the high electric field is applied during yarn manufacture (Persano et al., 2013). However, electrospinning methods can be difficult to adapt in order to produce continuous fibres. 9) Park et al., (2019) report the construction of piezoelectric nanofiber yarns via the same process as Ali et al., (2011), but without poling. PVDF-TrFE increases the beta phase and the dipoles are further aligned when the twist and pull electrospinning process is used. 10) Where some studies report issues of scale whereby the length of the nanofiber yarn depends on the size of the nanofiber web; methods using metal funnel cones and yarn spools (Ali et al., 2011) overcomes this. In the latter case, the limits of yarn length depends on the amount of solution loaded in the syringes.

[3] The amount of induced charges can be further enhanced by either increasing the contact area (Lin et al., 2013; Yu and Wang, 2016) or selecting yarns constructed of materials with a larger electron-affinity difference (in the case of inducing triboelectric effect).
[4] Fuh et al., 2015 and Yang et al., 2009c demonstrate similar responses.
[5] Molecular dipoles are randomly oriented, requiring additional poling (contact or corona) processes (Lund et al., 2018; Matsouka et al., 2017) under ultrahigh (~10MV/m) electric fields.



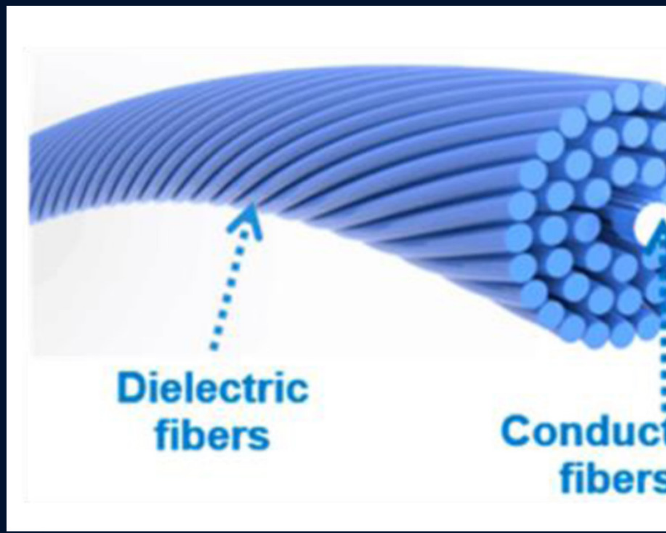


Figure 6.6 Combining yarns (Chung et al., 2018)

6.4 Interpreting the data to consider the construction of a mechanical stimuli hypothesis

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Figure 6.8 Simple graphical representation of yarn casing/ cladding

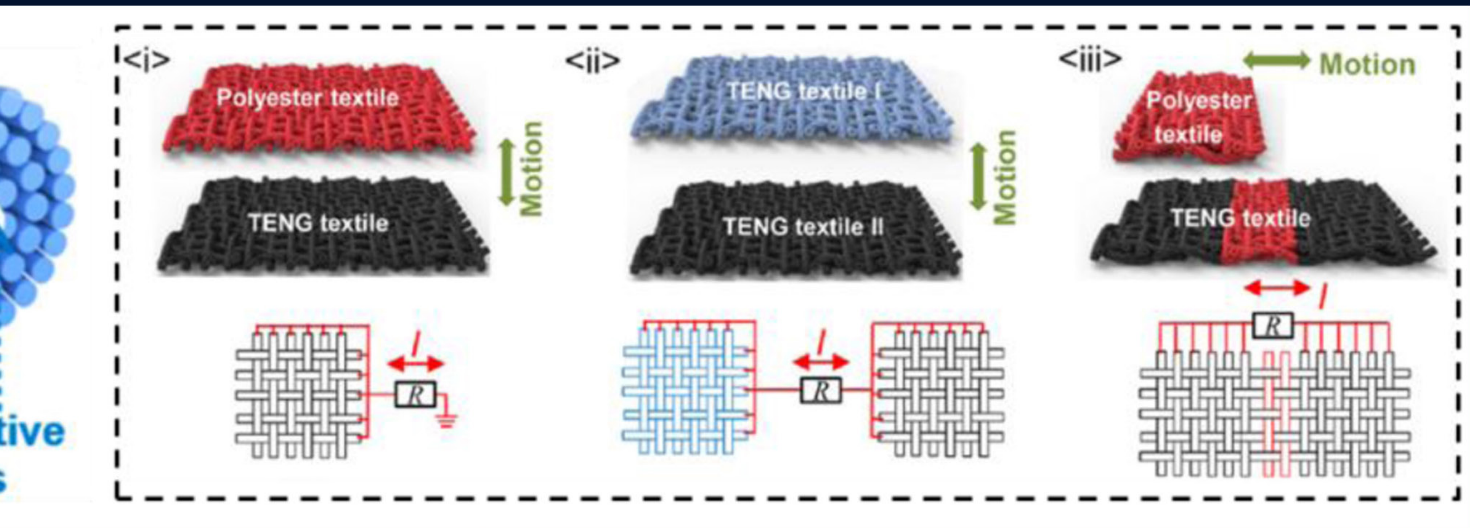

Figure 6.7 Yarn twisting (Yu et al., 2017)

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[6] The rise of alternative fashion brands including the Ministry of Supply (2020) demonstrate a focus on comfort, familiarity and expected 'norms'.

Figure. 6.9 LED-FSDs™ 'off' (Nolden, 2020)

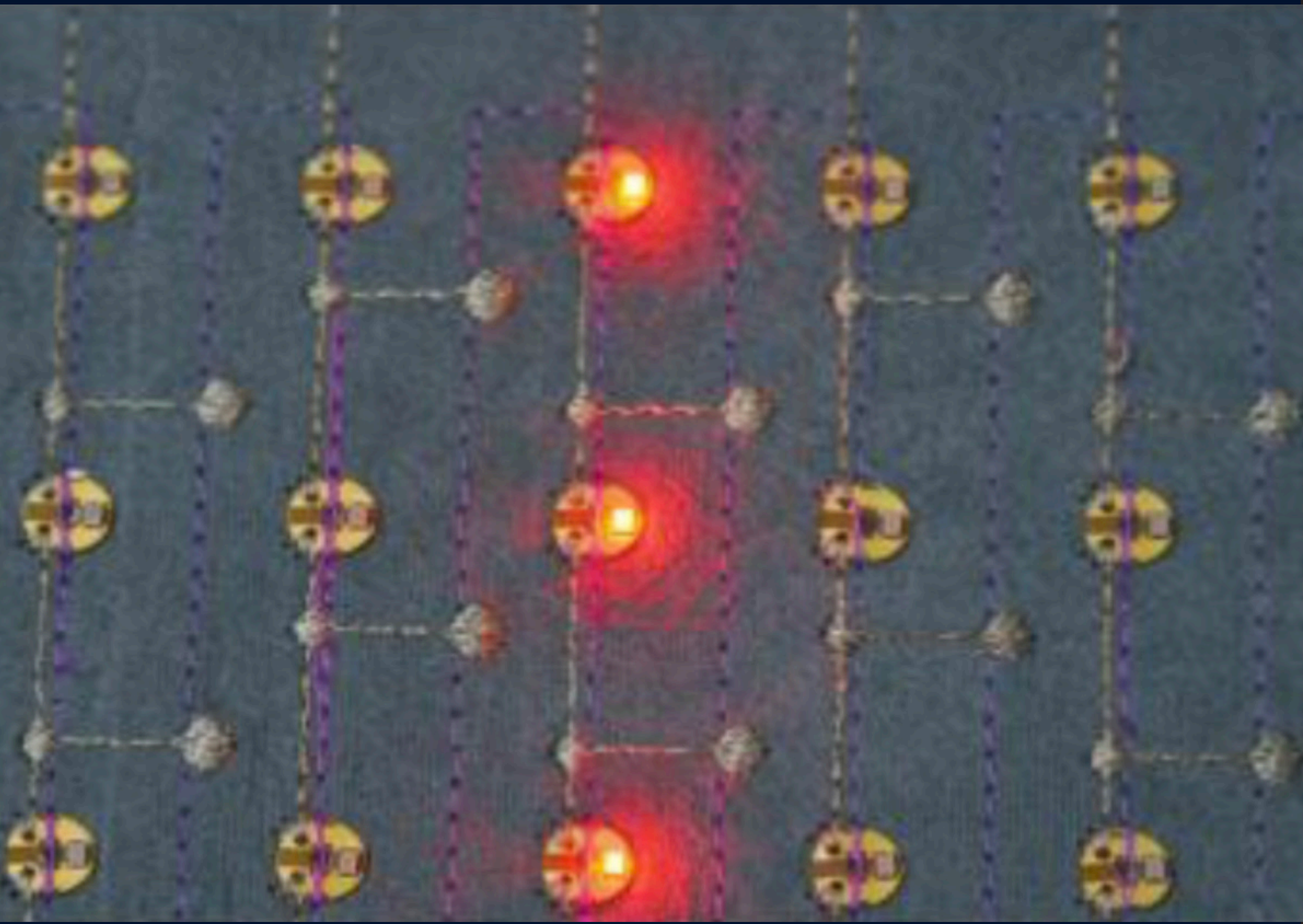

Figure. 6.10 LED-FSDs™ ‘on’ (Peters, 2014)

Figures 6.11 to 6.13 detail a range of considerations introducing a working hypothesis of a spec for the mechanical component [7]; laying down the foundations of exploratory work in this area.

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Figure. 6.11 Concept 1.0: ‘The bead’ - A ‘textile-based’ mechanical stimuli component (Salisbury, n.d. [b])

[7] UK. Patent applied for the ‘bead’ component. Application number 2013574.5, Salisbury, L.J, Royal College of Art [filed 28 August 2020] (Salisbury, n.d. [b]).

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Figure. 6.12 Concept 1.0: An overview of the integration of piezo yar

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rns as actuators within bead structures

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Figure. 6.13 Concept 2.0: ‘The bead’ with energy harvesting case (Salisbury, n.d. [b])

Table 6.14: A summary of key elements in Hypotheses 1.0 and 2.0

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Figure. 6.15 Simple graphical depiction of actuator positioning (Left: Actuator shaped around the full circumference of the casing; Right: Actuator focused in the centre of the casing [requires support frame])

Figure. 6.16 Iterations of bead case shapes [opposite page] (Salisbury, n.d. [b])

[8] 3D structures provide nearly five times the output power as 2D textile structures (Soin et al., 2014).
[9] Kim et al. (2018) demonstrated that the angle of the force corresponded to changes in maximum output power; a maximum output power of 0.064, 0.026 and 0.2 μW and a maximum output voltage of 1.75, 1.29 and 0.98V was observed from an impact force of 2Hz (4N) at angles of 0°, 45° and 90° respectively.
[10] Ponnamma et al. (2019b) demonstrate that mechanical vibrations display greater output voltage (12V) than the folding of the textile, or creasing (1.1V) and elbow movements (5.5V).

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Table 6.17: Power, force and preload hypothesised operation range

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6.5 Chapter Summary

The choice of materials used and combined to create e-textiles interventions holds importance; not solely in the performance of the components to deliver the functionality of the intervention, but also stakeholder experience. For example, the choice of piezo materials in this case study has the ability to reconsider the role of the wearer and the garment as a therapeutic device. If the piezo components are designed in a way that harvests energy from body movements, the wearer particpates in the delivery of care since they are required to contribute to the powering of the device. This is based on a behavioural method of intervening that may be making use of existing daily movements. This may be useful to some, in supporting a greater level of mobility, or a barrier to use for others; for example, if either they are unable to move enough so to generate enough energy, due to fatigue, injury, other co-morbidities and/or motor function.

Moreover, observation and thought should be given to what categories of people and

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impairment this may exclude, for example, those with more severe impairments. In this case, where the stimulation protocol is considered particularly useful for this group, the choice of materials may inadvertently exclude them.

But, it should be empasised that this approach is yet to be considered in terms of user feedback, which Chapter seven looks to explore.

Furthermore, there exists a range of challenges for using piezo materials from a technical point of view, specifically in being produced in a form that can be suitably integrated into the garment whilst meeting the requirements of the stimulation protocol, which this chapter has begun to demonstrate. Such challenges include:

a) Obtaining a significant beta phase fraction through orientation of dipoles.
This may be achieved by the use of fillers (see Appendix 2.3) or copolymerisation;
b) A flexibility and breathability that suits textile based applications.
This is difficult when using brittle inorganic ceramic-based materials, but made possible by either using polymer-based alternatives, which can present a further challenge of reduced piezoelectric effect compared to ceramic-based counterparts, or combining the two together.

The range of variables included in Section 6.4 will be explored through experimental approaches in the following chapters (seven, eight and nine). Chapter seven proceeds by investigating perceived levels of 'wearability' of various forms of PVDF in textiles with the participant group.
It may be necessary to reconsider the methods of processing piezo materials, their form and size and/or considering alternative material choices by reflecting back on findings in Chapter five. The remaining chapters will build on this, demonstrating the final hypothesis in Chapter nine.

Beyond this, this chapter introduces the importance of considering the form in which the material choice is developed to deliver the stimulation protocol. This takes into consideration findings from Chapters two and three, demonstrating the importance of how familiar the therapeutic intervention is and how it fits into everyday life. As this chapter arrives at the bead as an appealing tool for attending to these points, the motivations for creating beads to deliver the stimulation protocol in a garment are reflected upon. These can be summarised as follows:

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5. Considering the integration into manufacturing processes, threading beads onto yarns can act both as a way of attaching the component in a familiar manner to garment construction processes, but also a method for connecting to conductive yarns or wires when building into a larger e-textiles system in the garment.

Risks of using beads, or small components, are also considered both in this chapter and Chapter five:

1. It may be easily lost if not suitably attached to the garment in the manufacturing process or if the garment is damaged. Therefore the bead will require replacing, but it may also pollute the environment, and become a hazardous item that may be ingested accidentally as a result.

2. It is challenging to achieve the configuration of elements within the small nature of the bead and therefore the bead shape and size may be altered as a result which could, in turn affect the optimum shaping for delivery of force to the muscle.

Where this chapter has explored the compatibility of use of piezo materials to the intervention from a theoretical perspective, Chapter eight will conduct a range of experiments to evaluate this from a practice-based perspective. But first, Chapter seven will seek stakeholder feedback to take on board factors that may influence ‘wearability’, specifically softness and comfort, informing developments in Chapter eight.

CHAPTER 7.0

Manipulating textile softness: The application of piezoelectric material via sampling and focus group enquiry

Softness

“Related to flexibility, compression and/or to smoothness, quantifiable by a range of experimental tools. Perce body conditions as much as the textile, albeit largely by the aforementioned textile properties” (Salisbury, n.d. [a])

Comfort

“A feeling absent of pain/discomfort generated and dependent upon the following factors: (a) ‘Climatic variab include temperature, humidity and airflow; (b) ‘Textile properties’ including stretch, porosity, compression; (c) ‘Emotio (Salisbury, n.d. [a])

7.1 Chapter 7.0 Overview

'Softness' is a value that holds influence on 'wearability' (Salisbury, n.d. [a]), and appreciated within the textile industry. Notably, the *"aftercare of a garment frequently involves the use of softeners; '[They] are the most important global textile finishing chemicals in terms of value and amount [used]'"* (Choudhury, 2017 in Salisbury, n.d. [a]). Where the literature surrounding piezoelectric materials focuses for the most part on functional performance and some elements concerning wearability; using terms such as 'flexible', 'breathable' and 'wearable', there are limited considerations for the impact of the handle, softness and garment aesthetic when developing functional textile-based materials. *"Rarely, is there a consideration for degrees of comfort, specifically 'softness'. Yet, if such methods are to become integrated into wearable garments and worn on a daily basis, or even in niche contexts, the tactile experience requires attention"* (Salisbury, n.d. [a])[1].

In its role as a therapeutic intervention, comfort levels can have detrimental effects on the wearers' compliance of wearing the garment and therefore receiving 'treatment'. The following Chapter (seven) addresses the importance of this, establishing a range of focus groups (Stage five in Figure 0.1.3) alongside ongoing participatory design workshops. The Chapter will firstly summarise the definition of softness along with manners in which it is currently measured (Section 7.2.1 and 7.2.2). The participant-led methods used within this thesis will then be explained, along with the structure of the focus group enquiries (Section 7.2.3), before presenting key findings (Section 7.3); contributing to the working hypothesis.

Although the research places an emphasis on the subjective interpretations of 'softness' and 'comfort' by the participants, the chapter begins by introducing the following broad definitions to place this into perspective for quantitative analysis/discussion:

eived softness is context dependent and a personal experience that can differ from person-to-person; influenced by

les' externally (from the environment), internally (from the wearer), and the space between the textile and body. These nal and physical state of the wearer' which encompasses context (including health) and mood-depended experiences"

[1] Additional data can be found in Salisbury, n.d. [a]

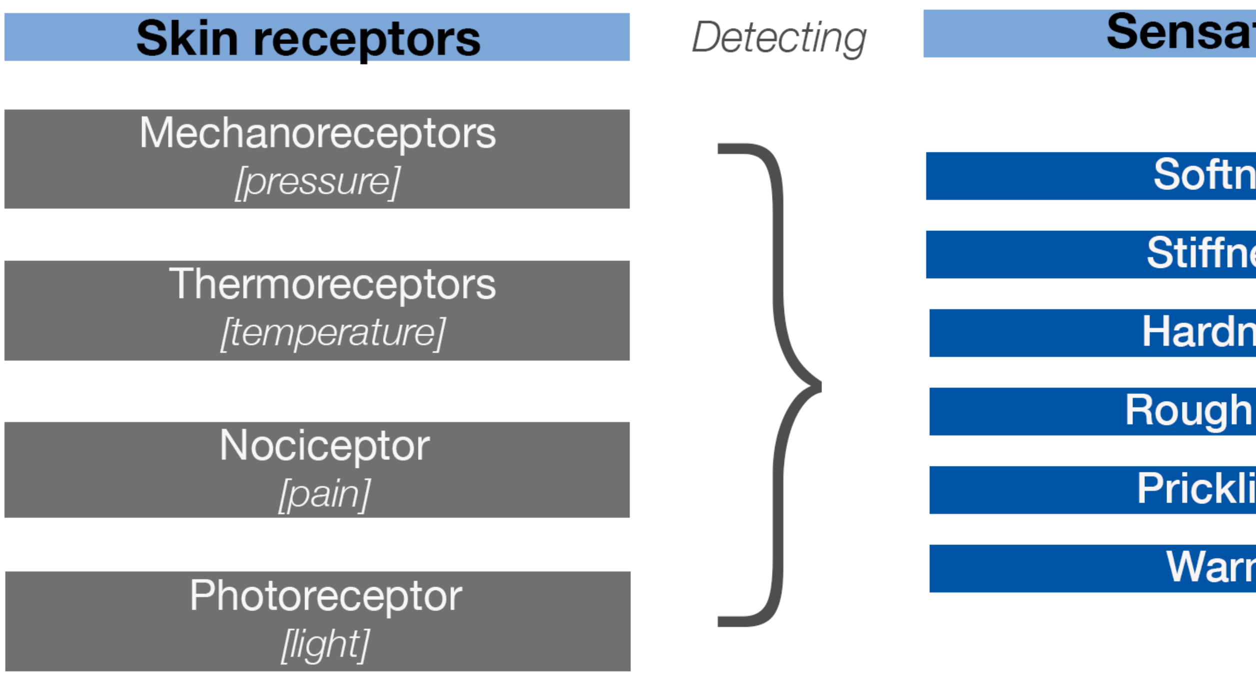
7.2 Experimental aims and methods for exploring degrees of 'softness'

7.2.1 Defining softness

'Softness' is one characteristic or 'sensation' (Peirce, 1930) amongst many others (Table 7.1), which comes to define the tactile property of a textile (Kilinc- Balci, 2011). The subjective nature of experiencing 'softness' is complex. The handle of a textile is determined by softness, as well as other factors including twist, count, friction, flexural rigidity, stiffness and 'hairiness' (Li and Wong, 2006). These interconnected 'sensations' have come to be defined through associations with hysteresis, tensile properties, and shear stiffness (Abbot, 1951; Bishop; 2008; 1997; 1996; Sun, 2018); via compressive qualities (Elder et al., 1984) or via a direct comparison to bending length (Peirce, 1930).

Within this study, people-centred approaches[4] are placed at the fore to determine sample softness, supplemented by quantitative data for sample thickness and stretch. Responses were considered in terms of heightened degrees of sensitivity[5] and repeated a week later to see if perceptions had changed. Table 7.1 summarises the correspondence between the body, sensations and fabric properties.

Table 7.1: A summary of the sensations related to fabric properties and the relevant skin receptors within a textile: body dialogue



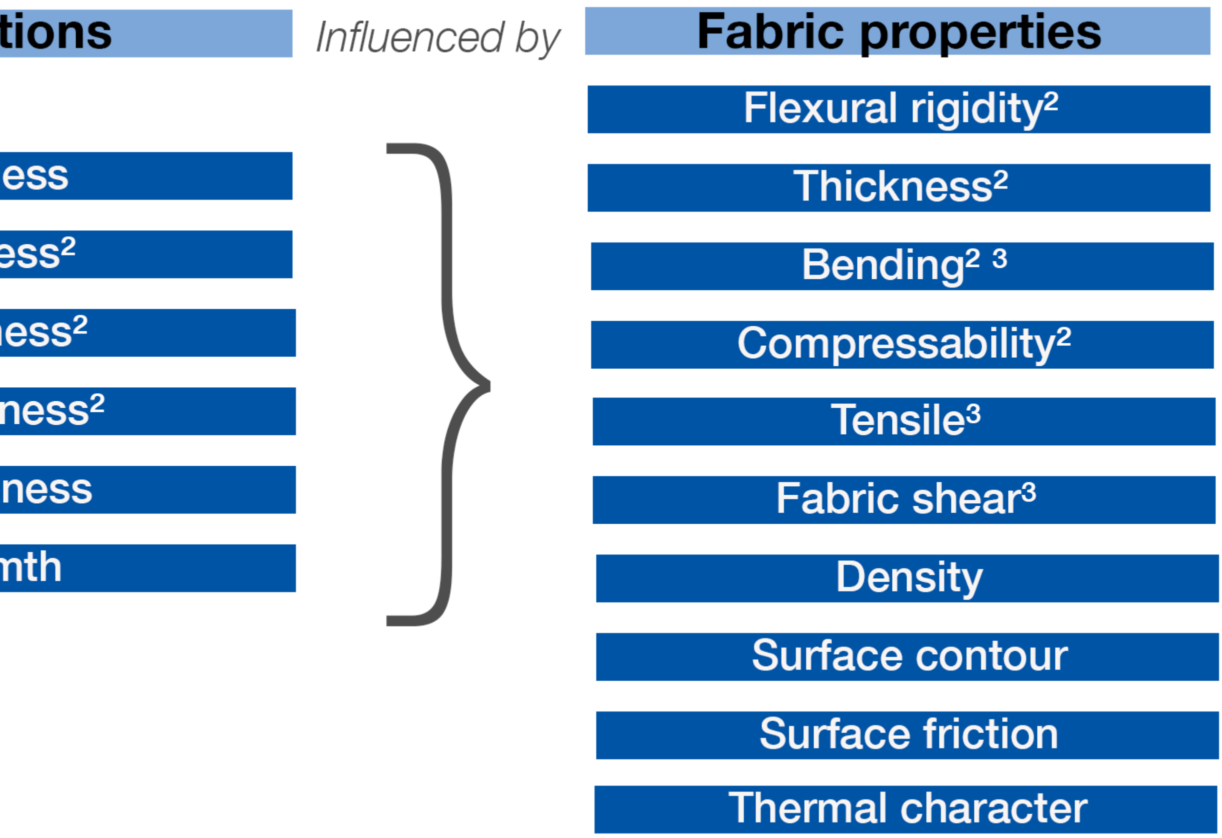
[2] Peirce, 1930
[3] Lindberg et al., 1961
[4] Subjective measures have been previously used within the literature: Winakor et al., 1980; F
2003; Soufflet et al., 2004; Sular and Okur, 2008; with the AATCC (2006) standard 'Fabric Han
for the Subjective Evalutation' providing guidance for subjective analysis. The 'Tactile Triangle
al., 2016) was constructed due to a disparity in opinion with the AATCC standard, suggesting that it "promote[s] unnatural interactions with textiles and so are incompatible with consumer experience" (ibid).
[5] "One in two stroke survivors experience impairment in touch sensation after stroke" (Goodin et al., 2018).

Fabric thickness and stretch ratio are included to observe any correlations between these properties and the level of softness; but more so, due to their significance in influencing garment type (e.g. for wearing underneath, or over other garments), seasonal and body temperature requirements, garment fit, bead positioning and level of indentation. As noted previously (Section 3.3.2, Chapter three), the distribution of tension within the textile also holds significance in its contribution towards ease of dressing and stimulation requirements. The tension, textile structure and yarn combination are therefore reported as factors that are modified during the sampling process.

7.2.2 Grading softness

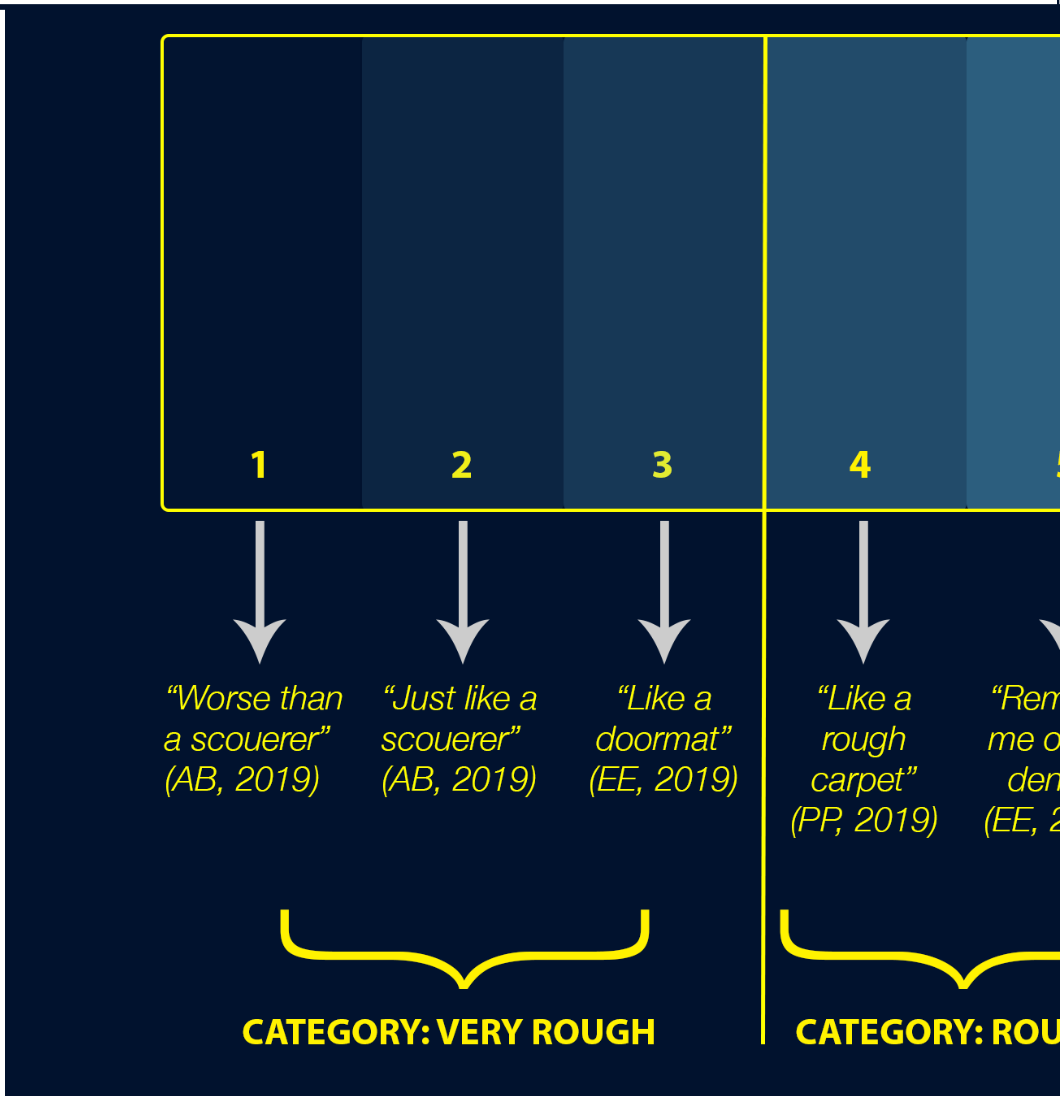
In contexts, such as the knit lab, participant presence can be limited, yet feedback is critical to the development process. To support the process of classifying degrees of softness by the researcher, a grading chart was created from participant feedback. The chart enabled the researcher to intermittently reflect on the perception of the textile from participants' perspectives whilst sampling. The researcher uses their own sensory experience to compare further samples produced in reference to prior graded samples. Samples produced in 'Sample Series II' were graded by participants to inform samples in 'Series III' which were also graded.

Participants made a comparative analysis of the samples, ranking them in order of softness relative to the other samples. All individual ranks were then averaged out. Discussions were then held within the groups to categorise the samples; using keywords



originating from participants to describe the tactile quality of the samples: 'Very rough', 'rough', 'wearable' and 'soft' (Figure 7.2).

Figure. 7.2 Softness level scale; categories and boundaries



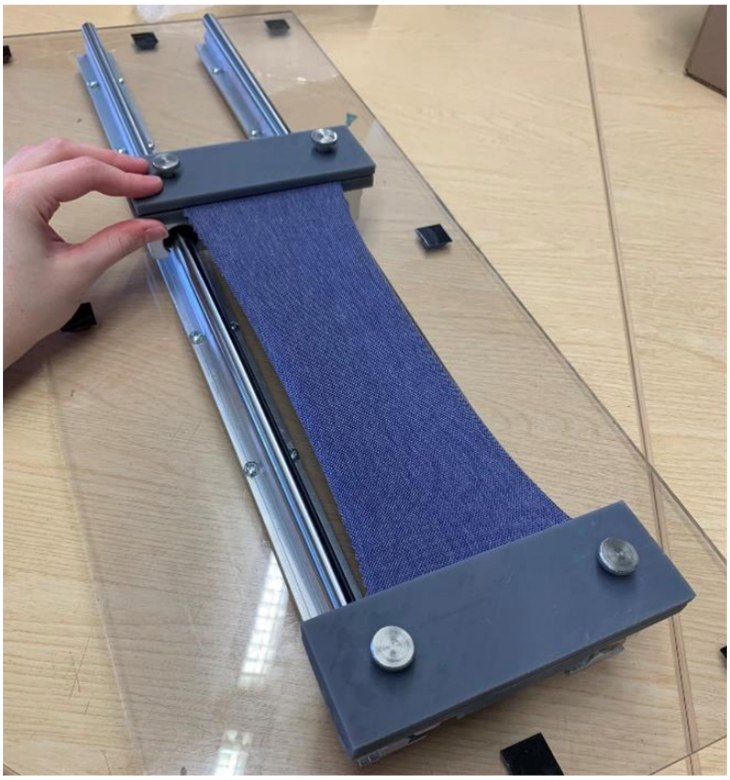
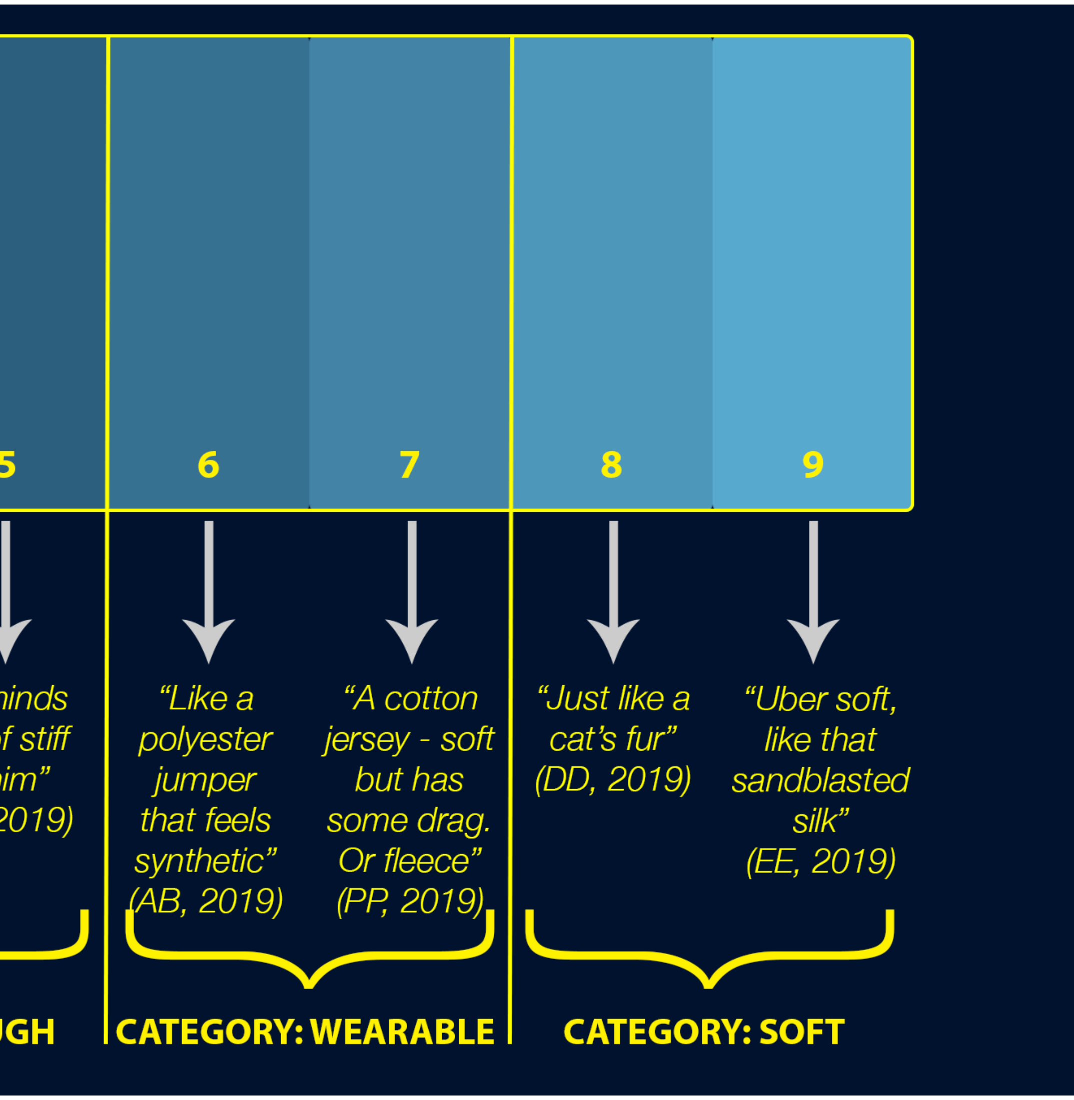


Figure. 7.3 Calculating the percentage stretch: Test textile stretched in test rig (Author's archive)



Stretch was calculated by clamping the textile within a test rig (Figure 7.3) and using the following equation:

Maximum stretch width [a] ÷ unstretched width [b] -1 x 100 = stretch percentage [c]

I.e.   a÷b -1 x 100 = c

Sample thickness was calculated using a digital calliper to a 0.01mm degree of accuracy.

7.2.3 Focus group and participatory design group structure

Focus groups were conducted over three months in various locations. The groups consisted of a 65:35 male to female ratio, of ages ranging from 25 to 70.

Textile samples (to an average scale of width [weft]: 15cm by length [warp]: 12cm) were created as provocations (Figure 7.5[6]; see Appendix 2.5 and 2.6 for experiment design) to explore participants’ views of:

i. Textile structure
ii. The form of the energy harvesting material
iii. The tactile experience of the samples
iv. Perceptions of self
v. Participant requirements and desires of a garment.

[6] Samples were removed from the acetate backing so that participants could handle them more easily.

Unlike the participatory groups, the focus groups were structured[7] to explore key questions (relating to points 'i.' to 'v.'). Table 7.4 demonstrates key features of the focus groups and participatory design group sessions.

Table 7.4: Comparing features of participatory design groups to focus groups

	Aims of the sessions	Duration *(mins per session)*	Total number of sessions	Research team[9 11] present	Number of participants *(per session)*	Approach
Participatory Design Group	1) Unpack participant needs within wearable healthcare contexts 2) Develop an understanding of participant experiences of wearing garments 3) Work with participants to develop early samples in line with needs and desires; informing the working hypothesis	60	36 [8]	4 [9]	6 [10]	Participant-led
Focus Group	1) To understand the suitability of concepts to everyday needs 2) To develop the hypothesis by exploring sample 'softness'	20	21	4 [11]	2 [12]	Researcher-led

Figure. 7.5 A snapshot of samples and participant interaction (Author's archive)

Feedback was obtained through independent review, led by researchers who had not previously met the participants, but who knew the research. This was important since participants had worked with the researcher (Salisbury) for over 12 months at this point, which was considered to bias responses. Participants had not previously seen the samples or been informed of the textile-stimulation concept explored.

The structure of enquiry within the focus group of ‘Sample Series I’ differed from Sample Series II and III. Further details are sub-headed accordingly.

7.2.3.1 Sample Series I

This enquiry took place in several steps:

Step one
Participants were asked to review a range of textile samples (Table 7.6), some of which contained piezoelectric films and conductive inks (Table 7.7). At this point, the functionality of the textile was not disclosed to participants. They were instead asked which samples they liked the most and that they would wear, and which ones they preferred the least and why.

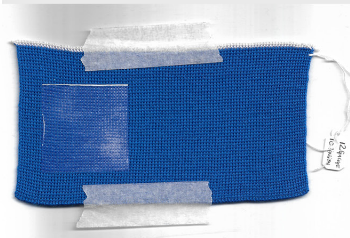
Step two
Participants were asked to examine a sample engineered according to the needs of the concept[13] (Figure 7.8). Again the participants were not informed about the function.

Step three
Further samples were presented to the participants which incorporated the PVDF yarn into the textile construction (Samples 32-36 in Table 7.9). Again, the function was not disclosed to participants.

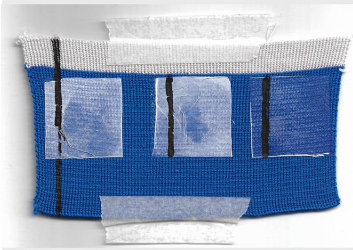
Step four
The function of the textile was finally disclosed, enabling the researcher(s) to capture participants’ perception of the handle and aesthetic in comparison to functionality of the samples.

[7] See question guide in Appendix 3.6
[8] Sessions conducted on a bi-monthly basis.
[9] e.g. Salisbury (co-facilitator); Support worker (co-facilitator); Two volunteers (supporting participants in practical work).
[10] Not including carer(s) who accompany some participants.
[11] 21 per each cycle; three cycles of focus groups were conducted e.g. two independent researchers (focus group leads and interviewers); Support worker (facilitator); Salisbury (observer).
[12] One-to-one sessions provided for individuals who were likely to agree with the other participant’s comments in a group scenario
[13] Raised tubular structures to generate higher contact of the stimulation site with the body. Drop stitch to enhance the looseness of movement of the piezoelectric yarn in contrast to tighter textile structures in Figure 7.7.

SAMPLE **1.**
Double bed knit (Tension: 9)



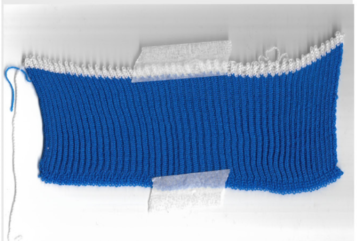
SAMPLE **2.**
Half Milano (Tension: 10)



SAMPLE **3.**
Full Milano (Tension 9)

SAMPLE **4.**
Half Cardigan (

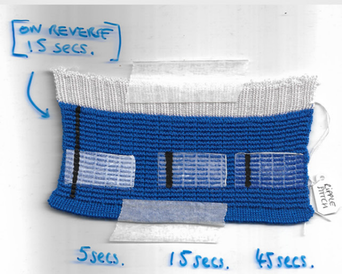
SAMPLE **8.**
1x1 Rib (Tension 11.5)



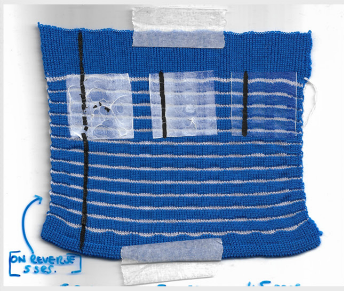
SAMPLE **9.**
1x1 Fishermans Rib
(Tension 9)

SAMPLE **10.**
2x1 Rib (Tension 9)

SAMPLE **11.**
2x2 Rib (Tensio



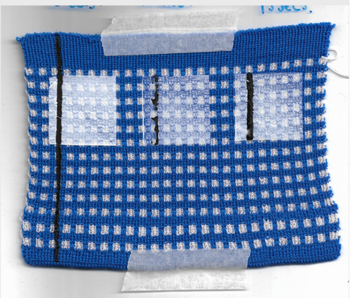
SAMPLE **15.**
Ripple Stitch (Tension 9)



SAMPLE **16. Holding Check**
(Tension 10.5)

SAMPLE **17.**
Drop Stitch (Tension 10.5)

SAMPLE **18.**
Plush
(Tension: 11.5 [I

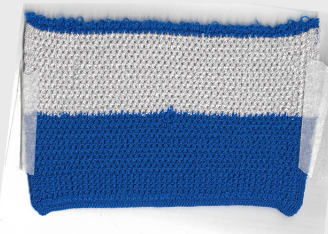


SAMPLE **22.**
Holding (Tension 10)

SAMPLE **23. Chevrons**
(Tension 10.5)

SAMPLE **24.**
Scalloped Edge (Tension 10)

SAMPLE **25.**
Cable (Tension



SAMPLE **29.**
Double bed Guilloche
(Tension 10.5)

Figure. 7.6 Photo compilation: Samples 1-30; 'Sample Series I'
(Author's archive)

(Tension 9)

SAMPLE **5.**
Full Cardigan with Tuck (Tension 9)

SAMPLE **6.**
Tubular knit (Tension 11.5)

SAMPLE **7.**
Single bed knit (Tension 11.5)

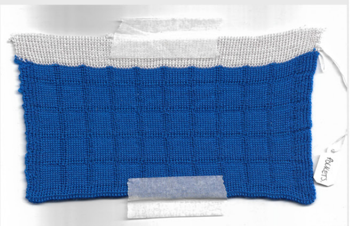
on 9)

SAMPLE **12.**
2x2 Rib Plaiting (Tension 11)

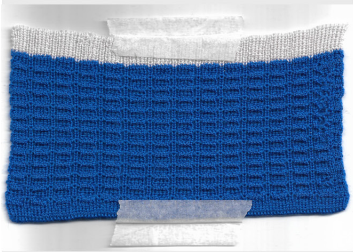
SAMPLE **13.**
Pleats (TEnsion 11)

SAMPLE **14. Racking (Tension 9)**

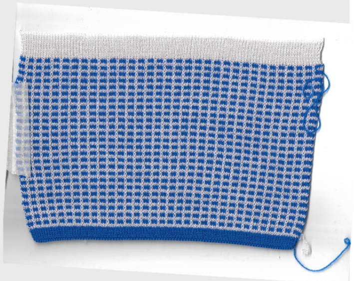
ack]; 8.5 [front])



SAMPLE **19. Pockets (Tension 10.5)**



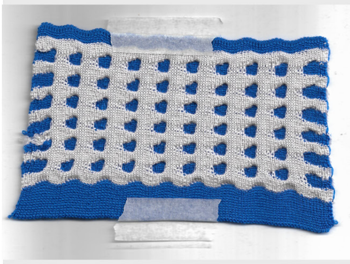
SAMPLE **20.**
Tucked Ripple Stitch (Tension 9)



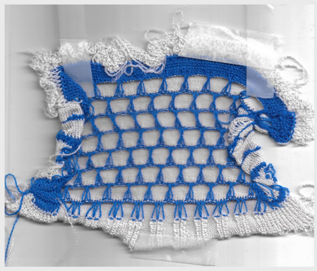
SAMPLE **21.**
Tucking (Tension 9)

n 9)

SAMPLE **26.**
Cables & Lace (Tension 9)



SAMPLE **27.**
Reversible Circles (Tension 9)



SAMPLE **28.**
Holding with Racked Transfers (Tension 9)

SAMPLE **30.**
Single bed Guilloche (Tension 10.5)

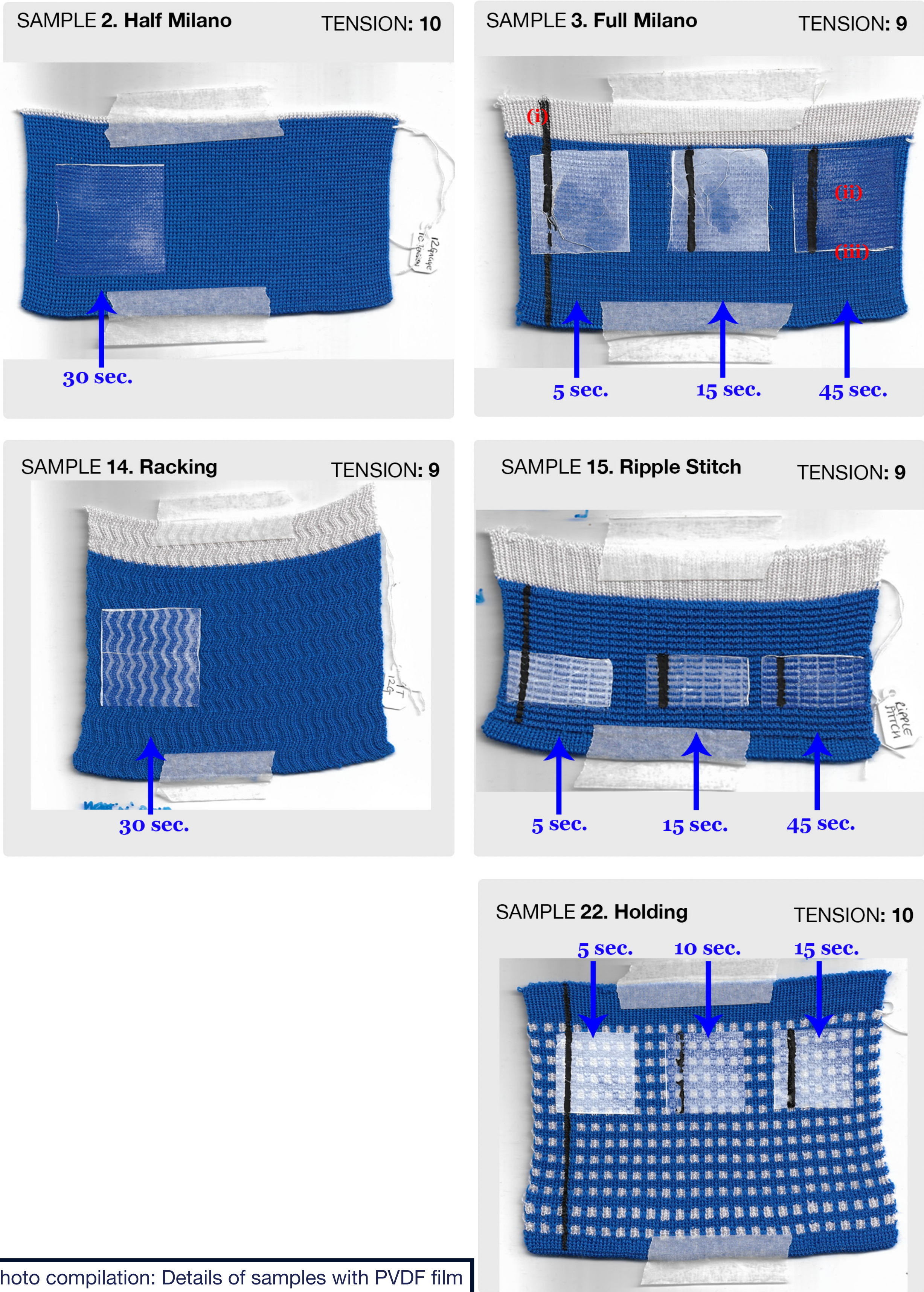
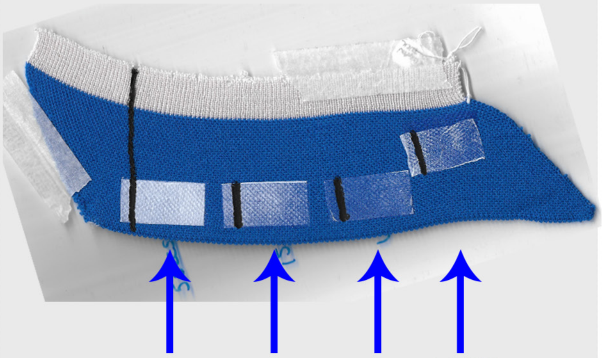
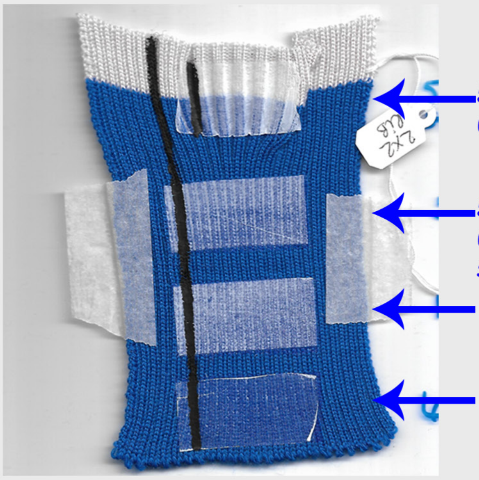


Figure. 7.7 Photo compilation: Details of samples with PVDF film (Author's archive)

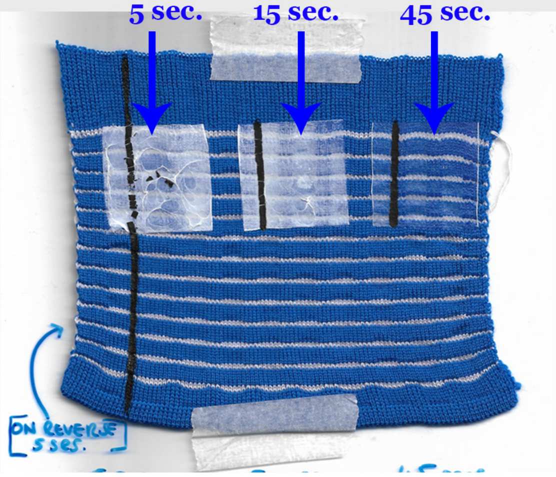
SAMPLE **5.** TENSION: **9**
Full Cardigan with Tuck



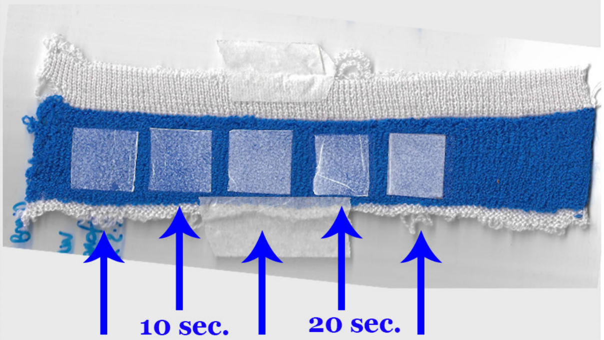
SAMPLE **11. 2x2 Rib** TENSION: **9**



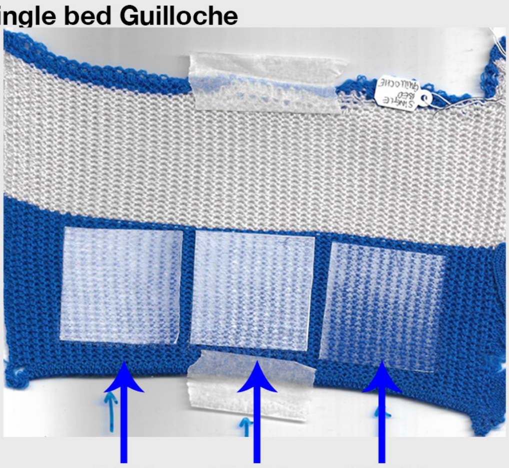
SAMPLE **16. Holding Check** TENSION: **10.5**



SAMPLE **18. Plush**
TENSION: **11.5***(back)*; **8.5***(front)*



SAMPLE **30.** TENSION: **10.5**
Single bed Guilloche



SAMPLE **31. Drop stitch RP**

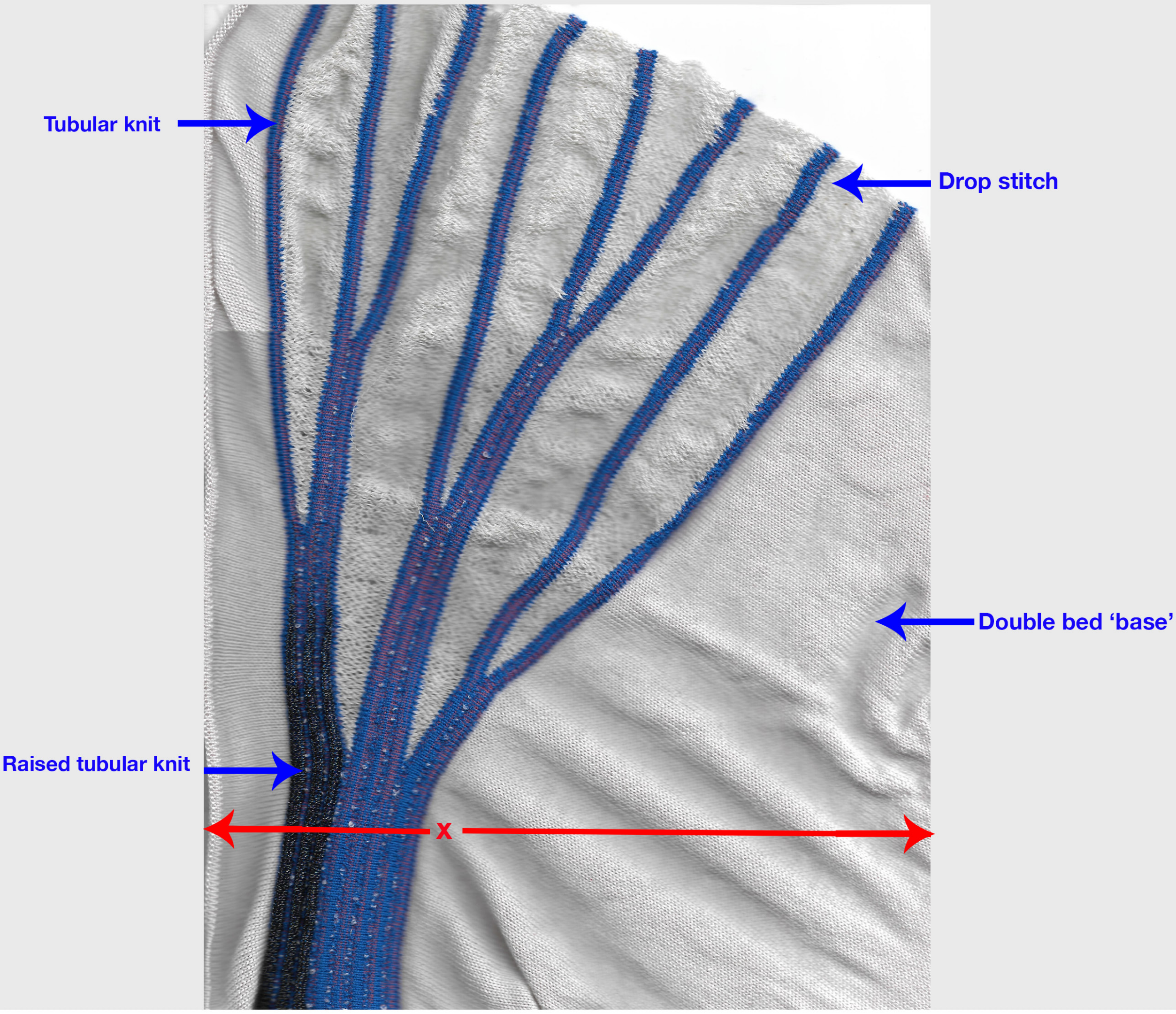
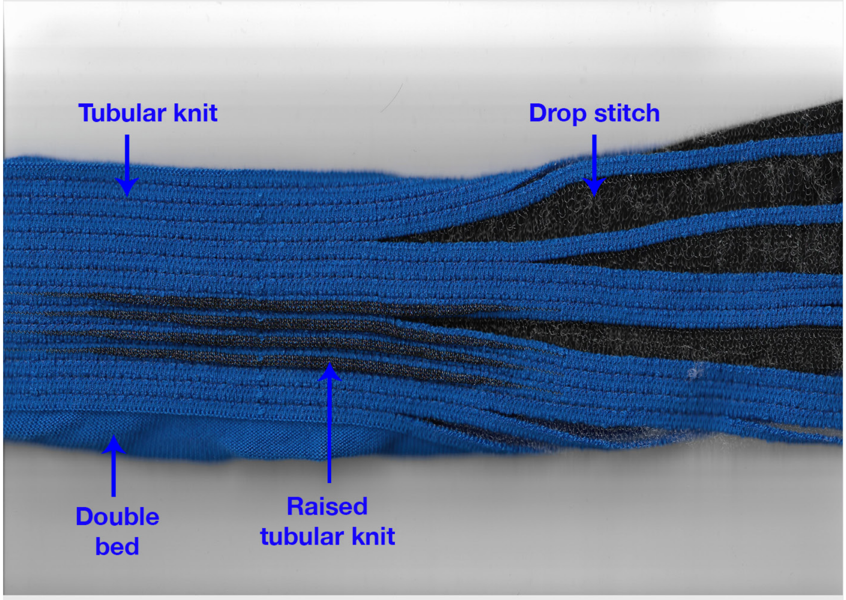


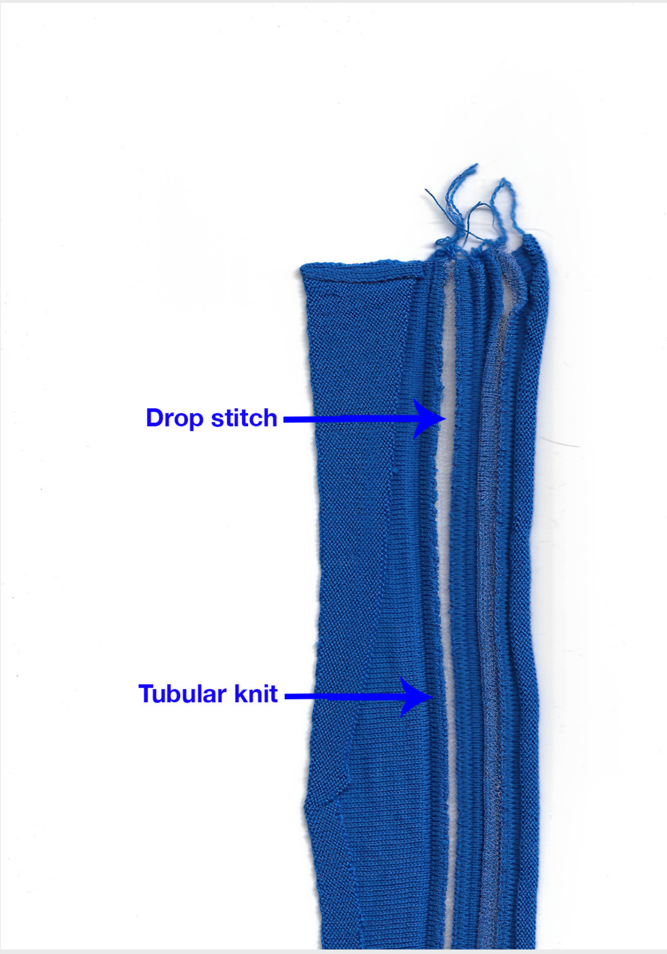
Figure. 7.8 Visual representation of Sample 31 (Author's archive)

SAMPLE **32. Drop stitch RP** *(PVDF)*



SAMPLE **33. Drop stitch RP** *PVDF*

Colour test with PVDF



SAMPLE **34. Half Milano RP** *PVDF*

Changing knit structure to half milano from drop stitch

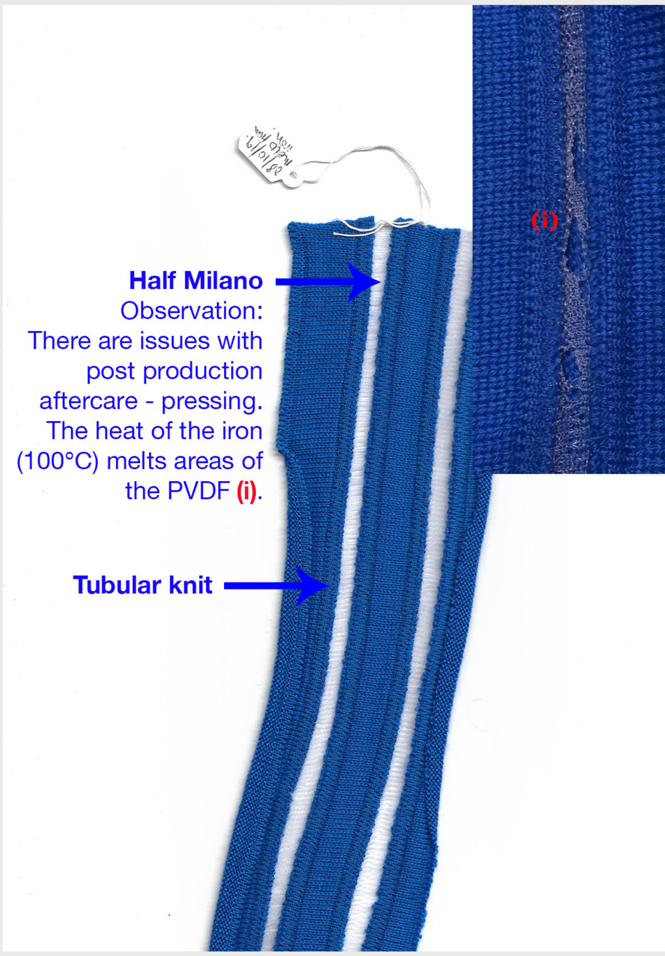
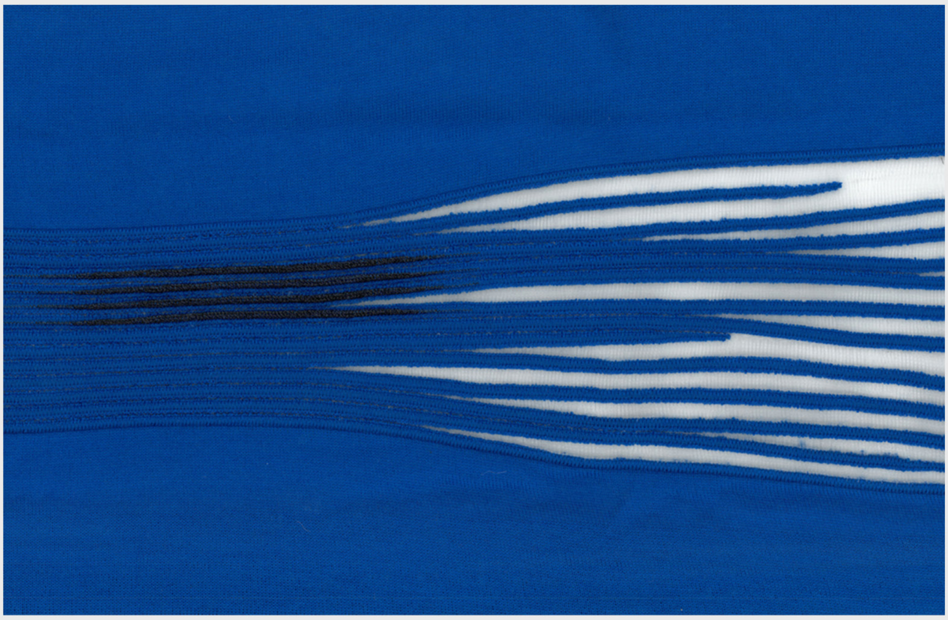


Figure. 7.9 Photo compilation: Sample 31 developments (Author's archive)

SAMPLE **32. Full view**

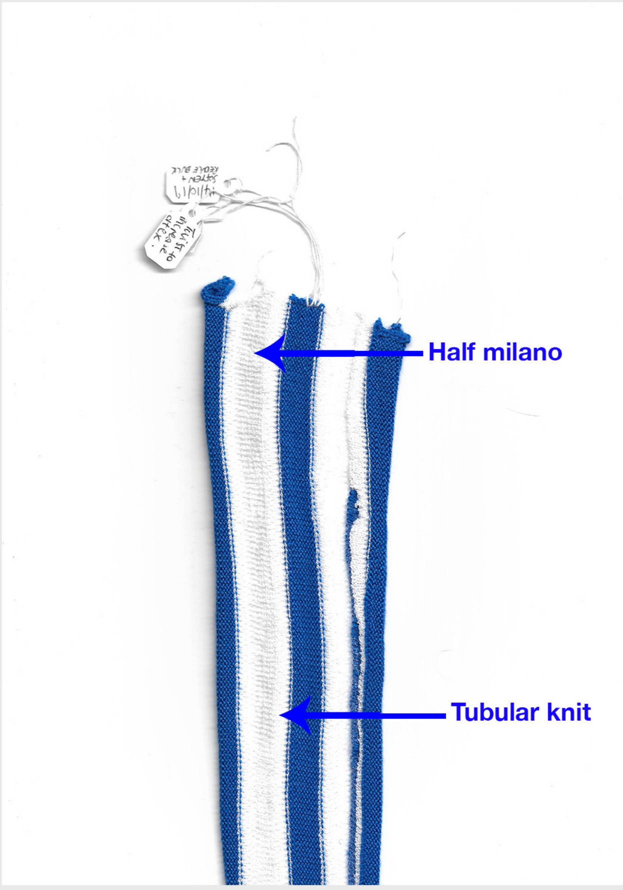


SAMPLE **35. Half Milano RP**

Texture change - replace PVDF with cashmere: unnamed metal and reduce bulk from 'veins'

SAMPLE **36. Half Milano RP** *PVDF*

Texture change - reduce bulk and improve texture of PVDF



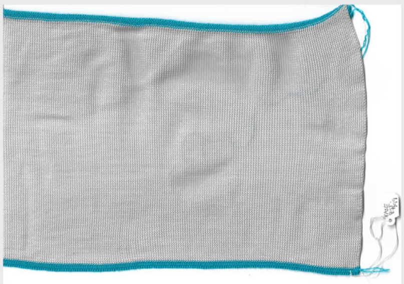
7.2.3.2 Sample Series II and III

Following on from Focus Group 1.0 conducted in ‘Sample Series I’, a participatory design approach (Sanders and Stappers, 2008) was used in the latter two series to inform the sampling and developments (Figures 7.10 to 7.12). This occurred on a weekly basis. Time between the sessions enabled sampling[14] to continue and for participants and the researcher to reflect on prior responses. The sessions therefore always began by revisiting findings from the previous session.

A grading chart was developed (see 7.2.2) following Focus Group 2.0, and renewed following Focus Group 3.0 where further samples were added.

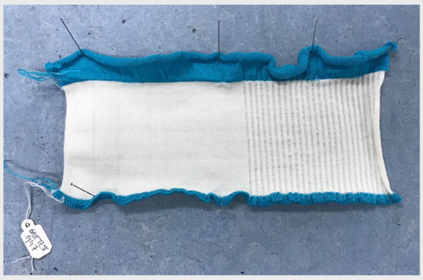
[14] Further details in Appendix 2.5

SAMPLE **37. Double bed**



SAMPLE **38. Double bed**

SAMPLE **39. Half milano (left); Mock rib (right).**



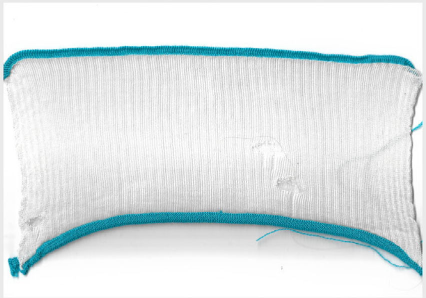
SAMPLE **40. Half milano (left); Mock rib (right).**

SAMPLE **41. Half cardigan**

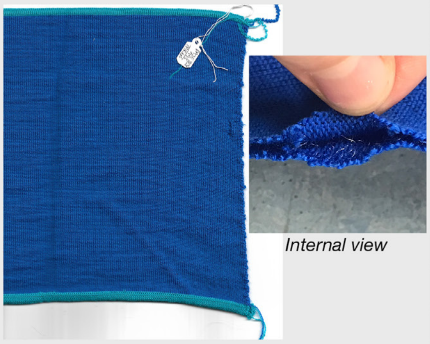
SAMPLE **42. Cardigan**

SAMPLE **43. 1x1 rib**

SAMPLE **44. Tubular spacer**



SAMPLE **45. Tubular spacer**



SAMPLE **46. Tubular spacer**

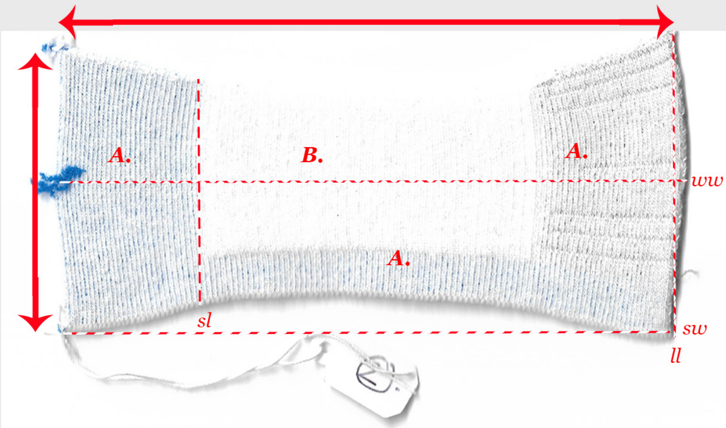
SAMPLE **47. Tubular spacer**

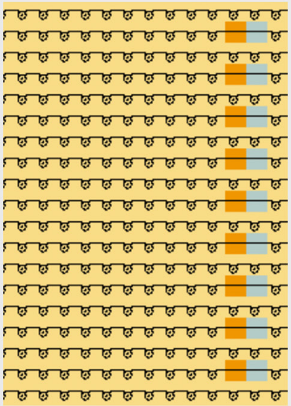
SAMPLE **48. Tubular spacer**

i) *Pink circles indicate considerations for bead position*

Figure. 7.10 Photo compilation: Sample photographs (Series II) (Author's archive)

SAMPLE **49. Tubular spacer**

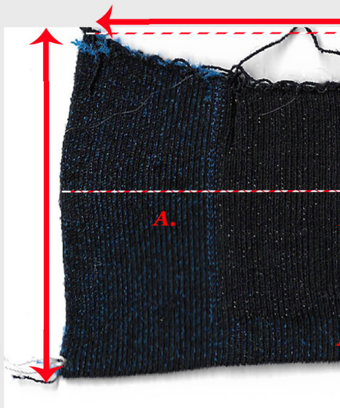




Widest width (ww): 13cm *Shortest width (sw): 12cm*
Longest length (ll): 6cm *Shortest length (sl): 4.5cm*

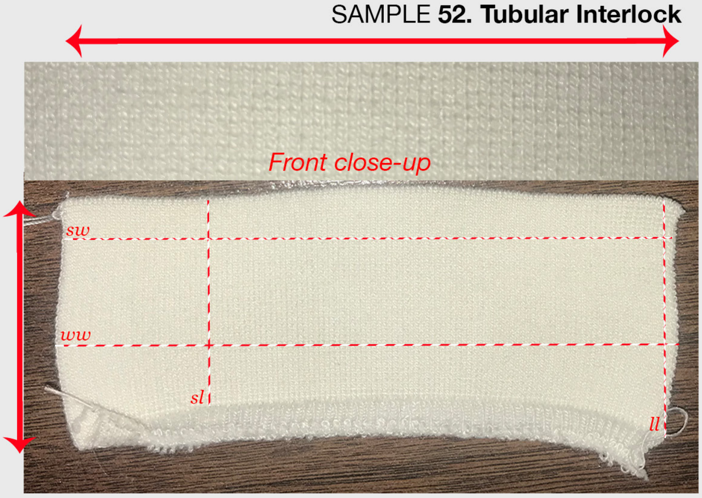
Above: Textile structure

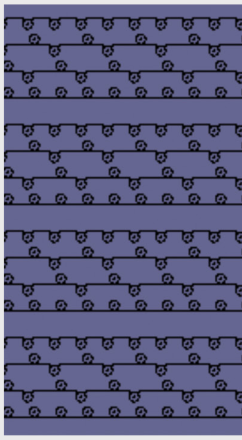
SAMPLE



Widest width (ww): 11cm
Longest length (ll): 6cm

SAMPLE **52. Tubular Interlock**

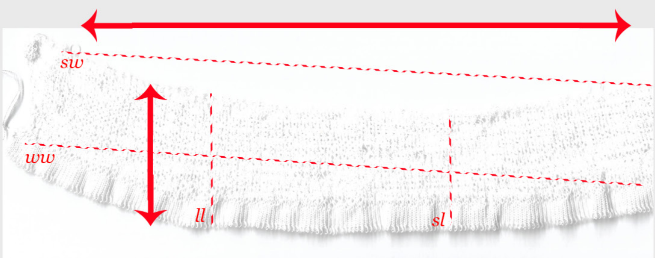


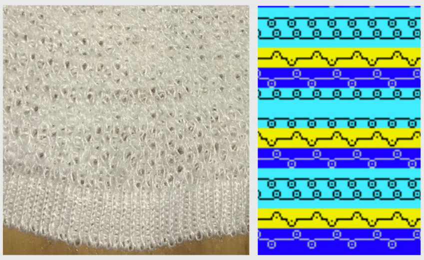


Widest width (ww): 12.5cm *Shortest width (sw): 12cm*
Longest length (ll): 5cm *Shortest length (sl): 4cm*

Above: Textile structu

SAMPLE **54. Tubular Interlock**

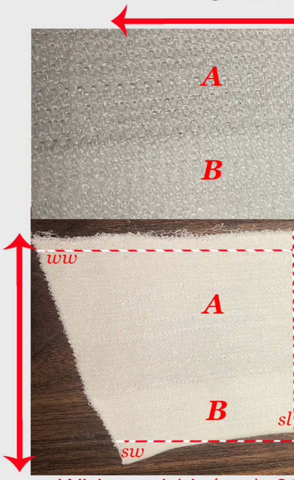




Widest width (ww): 32.5cm *Shortest width (sw): 31cm*
Longest length (ll): 4.5cm *Shortest length (sl): 4cm*

Above: Left - Close-up;
Right - Textile structure

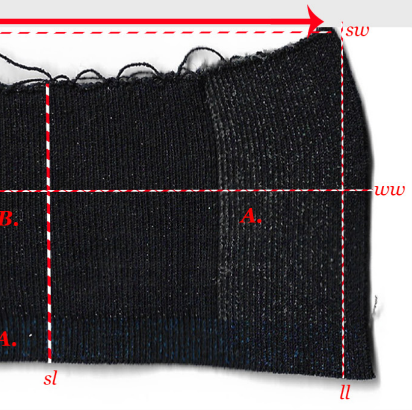
SAMPL



Widest width (ww): 36
Longest length (ll): 13

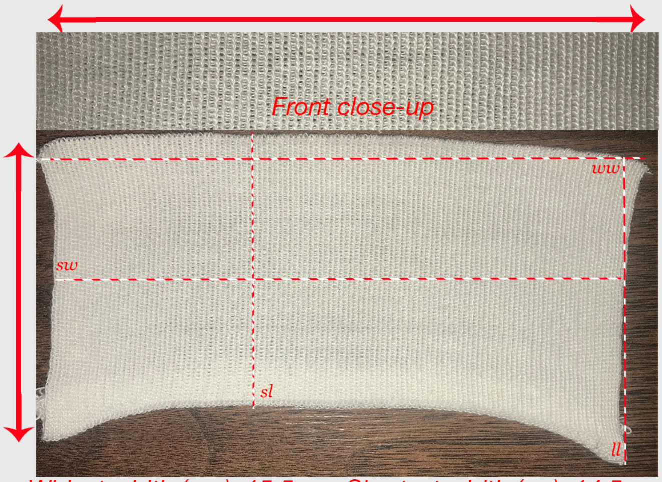
Figure. 7.11 Photo compilation: Sample photographs and key measurements (Series III) - Part 1 (Author's archive)

50. **Tubular spacer**

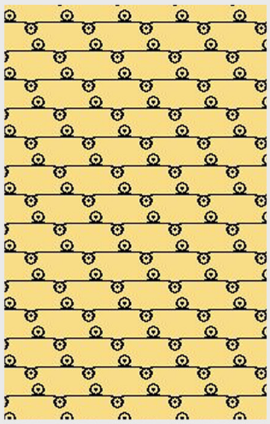


Shortest width (sw): 10cm
Shortest length (sl): 4.5cm

SAMPLE **51. Interlock**



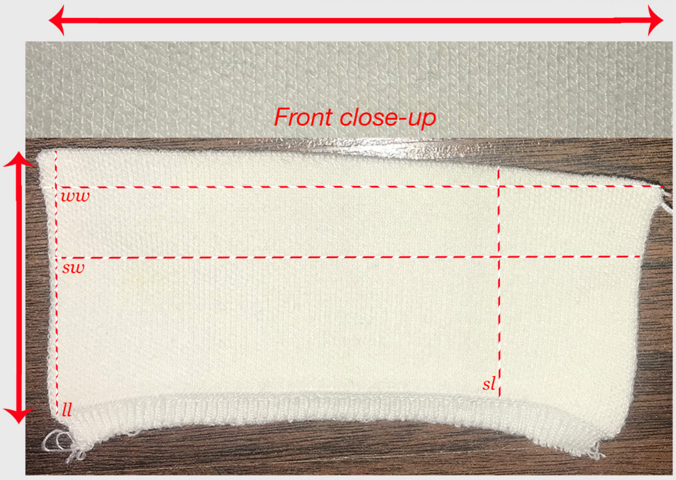
Widest width (ww): 15.5cm Shortest width (sw): 14.5cm
Longest length (ll): 7.5cm Shortest length (sl): 7cm



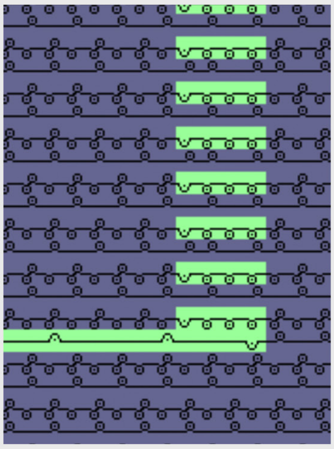
Above: Textile structure

ure

SAMPLE **53. Tubular Interlock**

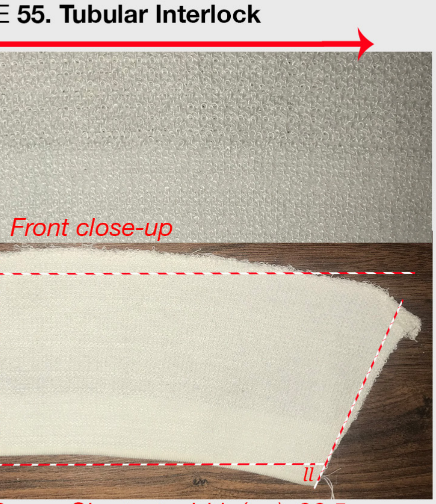


Widest width (ww): 13cm Shortest width (sw): 12.5cm
Longest length (ll): 5.5cm Shortest length (sl): 5cm



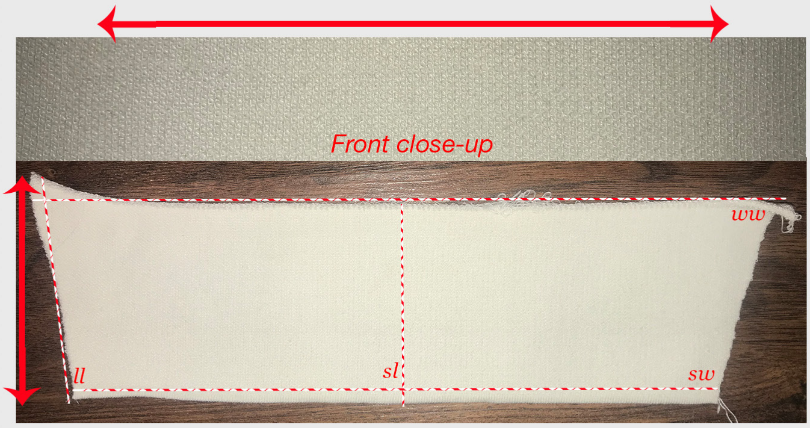
Above: Textile structure

E **55. Tubular Interlock**

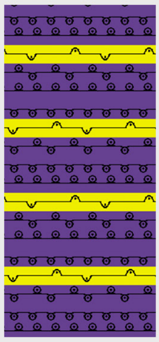


5cm Shortest width (sw): 26.5cm
3cm Shortest length (sl): 10.5cm

SAMPLE **56. Tubular Interlock**

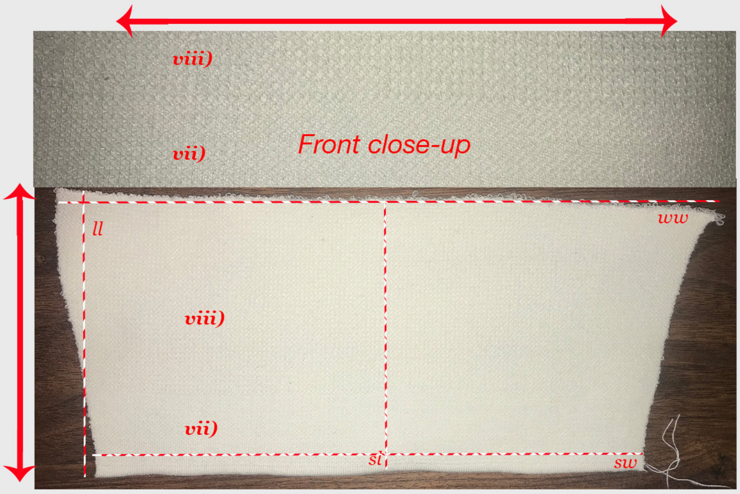


Widest width (ww): 30.5cm Shortest width (sw): 26.25cm
Longest length (ll): 9.5cm Shortest length (sl): 8cm



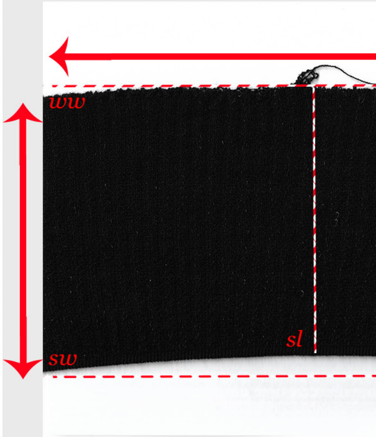
Above: Textile structure

SAMPLE **57. Tubular Interlock**



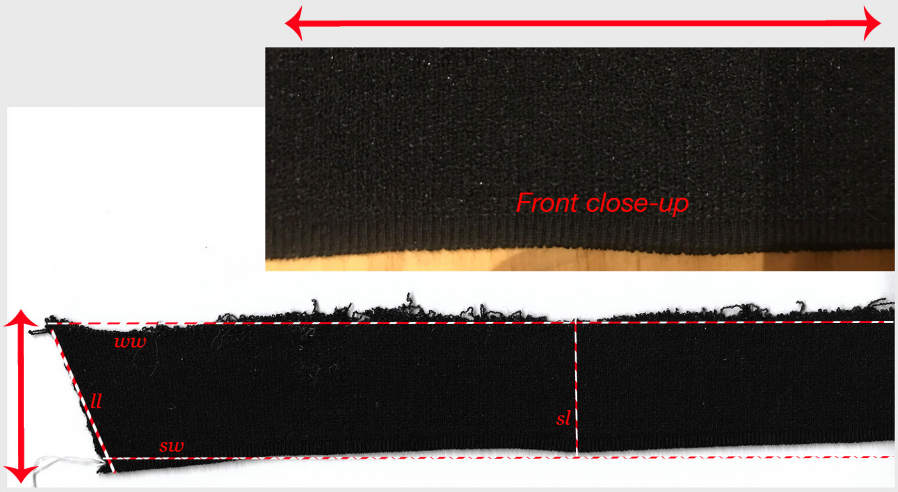
Widest width (ww): 29.5cm *Shortest width (sw): 24.5cm*
Longest length (ll): 13cm *Shortest length (sl): 12.5cm*

SAMPLE **58. Tub**

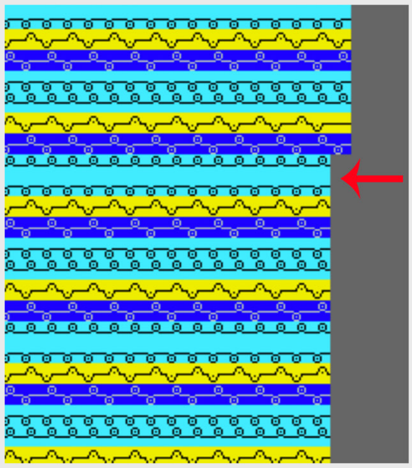


Widest width (ww): 46cm
Longest length (ll): 14.5cm

SAMPLE **59. Tubular Interlock**



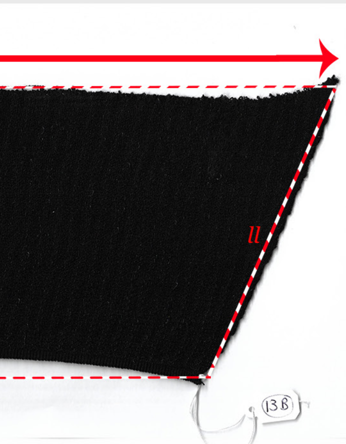
Widest width (ww): 34cm *Shortest width (sw): 31.5cm*
Longest length (ll): 4cm *Shortest length (sl): 5.25cm*



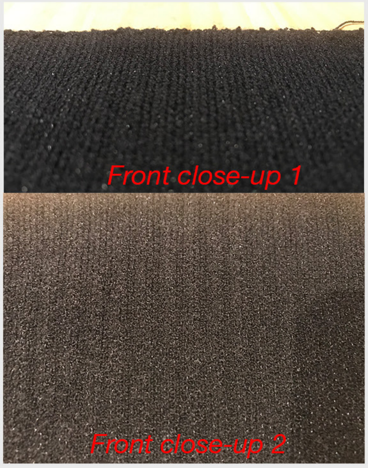
Above: Racking starting on tubular prevents yarn breaks

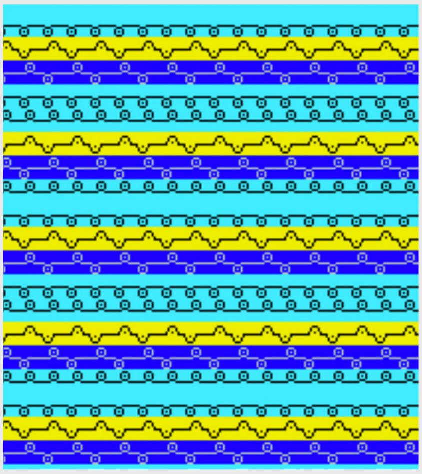
Figure. 7.12 Photo compilation: Sample photographs and key measurements (Series III) - Part 2 (Author's archive)

ular Interlock



Shortest width (sw): 34cm
Shortest length (sl): 11.5cm



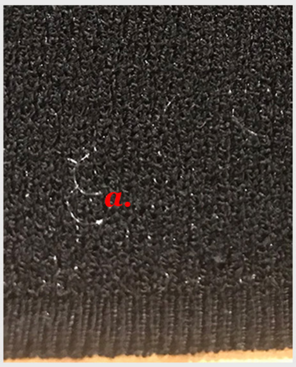


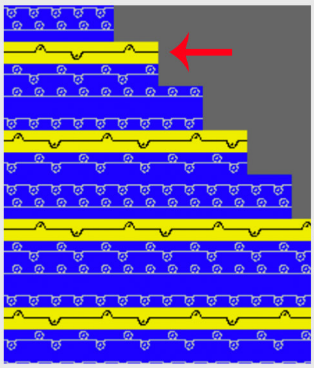
Above: Textile structure

SAMPLE **60. Tubular Interlock**

Widest width (ww): 23.5cm
Longest length (ll): 10.5cm

Shortest width (sw): 20cm
Shortest length (sl): 9cm





Above: Left - Broken PVDF [a];
Right - Racking starting on inlay (indicated by arrow)

7.2.4 Limitations and considerations

7.2.4.1 Focus groups

i) The yarn combinations used for the samples in each series was limited. This impacts the scope of the research and explorations of 'softness'. Since the use of wools was likely to lend itself to colder seasonal wear, this became the focus of the research. To counter this, discussions were held around spring and 'summer wear', with additional yarns (cotton and lycra) included for these purposes. Personal clothing and fabric swatches were referenced in cases where samples did not represent need.

ii) Only a limited number of samples featured the PVDF film or yarn. Their corresponding textile structures may have influenced responses.

iii) In the case of the PVDF film samples, it was observed that, as heat was applied for longer periods of time, the film became transparent (Figure 7.13). The PVDF may have subsequently dissolved into the adhesive, since areas not in contact with the adhesive remained white.

Figure. 7.13 Applying electrospun non-woven PVDF fibres to varying knit samples: time dependent reaction between the PVDF and adhesive (Author's archive)

iii) The colour of the samples was also limited, influencing participant responses; the off-white yarn influenced analogies of bandages (FF, 2019).

iv) The size of the samples limited the ability for some participants to visualise wearing a garment made out of the textile. Such participants instead reverted to commenting largely on the tactile experience, a valuable contribution to the early stages of enquiry. In other cases, participants began matching textiles together suggesting which areas of the garment may be constructed to form the sleeve, body, cuffs and hem (Figure 7.14); explored further in Chapter nine.

v) Samples 31 and 32 are characteristically unique in appearance, determined by the functional needs. Where no alternative 'unfamiliar' textile structures were tested, it is difficult to conclusively determine whether the participants liked or disliked the sample as a result of its distinct features or because of its 'unfamiliarity'. Therefore, participants were asked why they liked or disliked each sample they discussed.

7.2.4.2 Participatory design groups

i) Mood, seasons, weather and the context in which the sessions are held are all factors that can influence the response of participants. Although this cannot be fully mitigated, participatory groups were spaced out over a 24-month period in total, where behaviours, needs and desires could be analysed over various seasons and times of year.

ii) It was acknowledged that some individuals who did not take part at all could provide some additional, particularly important insights. A strategy was constructed to engage with them on a different level; e.g. on a one-to-one basis[15], or in consultation with the support worker who was either simply present or asked questions to the individuals on behalf of the researcher.

In cases where the participant did not meet the researcher (Salisbury) before, enquiries were conducted directly[16] and support was provided by support workers to include those with aphasia[16].

Figure. 7.14 A participant considering and selecting a choice of textile structures (Author's archive)

[15] Overwhelming auditory stimulation can limit participation for some individuals who experience heightened levels of sensitivity post-stroke.
[16] Figures 7.15 and 7.17 demonstrate examples. Note that in some cases participants respond for their own preferences, and in some cases, from observing others.

7.3 Findings and Discussion

7.3.1 Sample Series I

In step one, participants evaluated the samples and discussed their preferences to which they would most likely wear. This was initially determined by the pattern of the textile, but later came to be dominated by the level of softness. Although the same yarn was used to construct these samples (cash-wool), participant responses varied according to differing textile structures, influencing the level of perceived softness. Overall, participants preferred more uniform structures; 84% (Samples 1-12, 16, 19 and 21-24) compared to 24% of samples with more complex textures (e.g. 13-15, 17, 18, 20 and 25-30).

More complex patterns raised causes concern amongst a number of participants (8 participants: 24%). The overpowering nature of visual stimuli can present issues: *"You have to be careful because something like this [chevrons] is no good for me. It could trigger my epilepsy"* (MN, 2019).

The level of stretch which the textile exhibited was referenced regularly (56% of the time) in participants' responses. In particular, three participants suggested that their perceived value of the textile and its durability can be determined by the stretch. They noted that thicker textiles with a 'tighter' stretch were more robust and durable compared to other lighter, thinner and 'looser' stretch jumpers: *"[I like] a heavier jumper [like this (Tucked ripple stitch)] because thin ones tend to lose their stretch"* (CE, 2019).

A striking finding was the difference between responses to Sample 32. Prior to knowing the intended function of the textile (energy harvesting and stimulating), 97% of participants outrightly rejected Sample 32 stating they would not wear it. However, after disclosing the function only one individual (MN) retained their original decision to not wear it. 97% of the original 97% who had previously rejected the sample changed their minds, stating that they would now wear it due to the benefits the function could have on their recovery. The difference highlights the value of the concept. Comfort and visual appearance was seen to be marginalised or reduced in priority after the function of the 'device' was disclosed. This displays a disparity between quality of life versus immediate healthcare needs. It may be questioned why, for the majority of participants, the level of impact to health is valued above personal identity and comfort. In response to this, participants suggested that there was an expectation of having to sacrifice quality of life in order to recover, which is dependent on:

i) the level of benefit to health;
ii) the duration and frequency of wear.

Devices worn long-term require alternative considerations and additional needs to be met; although the same can be said for those worn for short periods of time; motivating people to wear and comply with wearing them in the first place. The level of comfort was an important factor in compliance with wear for short and long-term devices which, upon reflection, participants reconsidered shortly after initially responding that this did not matter.

Figure 7.15 Participant discussing sleeve length in response to Sample 31 (Author's archive)

Since sleeve length[17] and garment style was particularly commented on, further evaluations of whether the 'device' is a garment or perhaps a 'band' emerged (Table 7.16).

[17] Figure 9.2, Chapter nine.

Table 7.16: Benefits and limitations of the type of wearable

	Opportunity	Limitations
Garment	1) Familiarity 2) Styled: paired with other garments 3) Desirable 4) Easier to position: use the natural positioning of the garment and seams as a guide (ST, 2019) 5) Meets additional needs (e.g. body temperature requirements and considerations for identity)	1) Requires consideration and variety of options to meet social and cultural needs 2) Needs washing
Strap/ band	1) Doesn't need to be washed? 2) Less material so cheaper? 3) Can be worn under clothes 4) Less limited by style and fit	1) Highlights 'difference': "no-one wears a band round their arm" (CD, 2019) 2) "Still requires thought about how it looks and fits" (FF, 2019) 3) Difficult to position

At this stage it was unknown whether the approach to stimulation itself was driving the change in decision to wear Sample 32 and to what extent the context of the garment/ textile contributed towards this response. Therefore, participants were asked: if the stimulation could be provided in any textile structure from the samples available, which one they would choose (Figure 7.17). The majority of respondents (91%) chose a structure from Samples 1-30, with Samples 19 (pockets), 10 (2x1 rib) and 4 (half cardigan) being the most popular: *"If it was changed into something like that [drop stitch] then I would wear it outside"* (MM, 2019).

Figure 7.17 Participant response to Sample 32 (Author's archive)

7.3.2 Sample Series II

Participant responses centred around 4 key themes: references to 'softness', the type of garment they could identify the sample with, and considering the suitability of samples to seasonal weather requirements. The following findings have been divided accordingly.

7.3.2.1 Considering sample softness

Overall, participant responses emphasised the thickness, stretch and softness of the samples. Samples 41 - 43 were received with the greatest negativity, being described as 'rough', 'unwearable' and rejected: *"Oh this one is really rough. No, there's no way that this could be worn. It would scratch your skin off!"* (ibid).

Participants noted the weight of Sample 37 was noticeably more than other samples. This may hinder limb use, adding to the weight of the limb which is already a barrier (KK, 2019). The excessive use of Inox is seen to contribute to the weight; its use across the whole textile being further problematic without adequate insulation.
The use of Lycra increases the stretch ratio in Sample 38. However, it also contributes to a 'bandage' aesthetic (MM, 2019) and increases surface roughness (DF, 2019); the PVDF appears to be looping above the surface rather than sitting flat (Figure 7.18). The introduction of cash-metal to Section B of Sample 38 increases perceived softness from a visual, but not from a tactile perspective.

Figure 7.18 - Close-up of surface structure with protruding PVDF stitches (Author's archive)

7.3.2.2 Garment type

A common theme of 'essential wear'; i.e. garments that are worn on a daily basis emerged from discussions. This included basic jumpers, t-shirts and base layers[18]. *"You need it to be basic. Like a simple colour because it will be easier to wear"* (QQ, 2019).

Within the line of conversation, the level of stretch in the samples became a point of focus. Recalling Section 3.3.2 in Chapter three, participants revisited issues dressing into 'gym clothes' or 'tight fitting clothing', suggesting that the energy needed to dress can act as a barrier to them being able to wear 'high-stretch' clothes. Requirements of the fit of the garment may be a barrier to use since participants regularly reported wearing a bigger size in order to aid dressing: *"I wear extra large t-shirts because its much easier to dress in and I also get really hot now [after brain injury] so the space [between body and garment] cools me"* (PQ, 2019).

The fit of the garment was also important in reducing the level of stigma and highlighting disability: *"What concerns me is the fit of the garment. If the sleeve is positioned wrongly or the measurements are wrong it can make you look like you can't dress yourself or make people look at your arm more"* (JJ, 2019). 27% of participants recalled a change in body size post injury: *"Your body size changes after your injury. Some garments, you can't put on afterwards because your body doesn't move the same way, it changes shape and clothes just don't hang properly on the body in the same way anymore. Especially loose clothes"* (HH, 2019).

The importance of positioning and fit of the garment cannot be overlooked, since the 'bead' needs to be placed accurately at the site of stimulation (Figure 5.1) and suitably indent the arm.

Further conversations explored the level of trust in the garment, in knowing that the 'component' is doing what it is supposed to, and even trusting that it is worthwhile to use: *"How do you know that it is actually doing what it is supposed to? Do you feel something?"* (DF, 2019); *"Feeling the treatment would be a good way of knowing like you can feel something is happening"* (HH, 2019); *"But would that become annoying after a while? You wouldn't want that to happen all day would you"* (JJ, 2019); *"How would you stop it? You can't be taking off your top in the middle of the supermarket if it's annoying you [laughs]"* (DF, 2019). Participants highlighted the need to integrate buttons in order to start, stop and override the function, providing an element of control in the hands of the wearer.

Discussions also explored the manner in which the device is powered: *"So you'd have to do ten repetitions or such to get it going? That's all well and good to begin with but when you feel as tired as you can do [fatigue], then you probably wouldn't bother"* (RR, 2019); *"Can you not store some of the energy or get it from somewhere else, as like a backup or something?"* (DF, 2019); *"It's good that it motivates you to move to receive the treatment but what if you had just had the stroke? Or if you can't move much? Because this would be really useful for people like that but you need an alternative power as well for them"* (TT, 2019); *"Yeah and if you need to do too much, some people won't bother"* (CE, 2019).

[18] Sample structures 19, 10 and 4 were identified as being more 'familiar' to existing garments.

7.3.2.3 The influence of body temperature on textile properties

18% of participants made reference to an increase in body temperature post brain injury which has led them to wear lighter, thinner layers of clothing: *"Since my brain injury I'm hot all the time. So I just end up wearing large t-shirts. Even in winter I just wear light summer jackets"* (QR, 2019). On the other hand 27% of participants noted that they were more susceptible to feeling the cold after incurring the brain injury: *"Ever since the stroke I feel cold more often. It's horrible because it makes your [affected] arm more stiff and painful. That's why I wear these extra layers [draws attention to a long sleeve top worn underneath their clothing]"* (WX, 2019).

Participants also discussed the seasonal context for wearing the different samples: *"If you made a thin layer then you could wear it in summer and winter because you could just wear it under your jumper in winter, and wear it by itself in summer"* (RR, 2019).

7.3.3 Sample Series III

As a result of findings from 'Series II', which highlighted a need to measure sample softness, thickness and stretch levels, samples[19] were graded (Section 7.2.2) by participants (Figures 7.22 and 7.23), adding in samples created from 'Series III'. Averages of scores for stretch, thickness and tensions were calculated (Appendix 2.7). These have been summarised according to the numerical categories of softness in Figures 7.22 and 7.23. Key findings are presented below within the themes of 'Textile structure', 'Sample thickness, yarn combination and arrangement' and 'Tension'.

7.3.3.1 Textile structure

By employing spacer structures, the PVDF yarn could be tucked in between the two outer layers of the textile (Figure 7.19). In this instance the two outer layers of the textile contributed more to surface texture; catching the PVDF yarn within the textile and reducing contact of the PVDF with the skin. Samples employing a spacer structure saw an increase in sample softness to 7 and 8 (Samples 44 and 45 respectively). Softness levels were all below 6 in Samples 37 to 42, and as low as 1 (Sample 43) and 2 (Samples 41 and 42).

Spacer structures are also noted useful for improving energy harvesting output performance. Soin et al. (2014) have demonstrated higher outputs and efficiencies of spacer structures versus '2D' woven, knit and non-wovens; with a maximum output power density of 5.10μWcm-2 (under pressures of 0.02 - 0.10 MPa).

Samples using spacer structures tended to increase sample thickness (up to 65mm reported on warp knitted spacers; Yip and Ng, 2008; Hou et al., 2012). Depending on yarn combinations and tension, tubular structures are notably thicker than full interlock (Sample 2 compared to Sample 3 on average). By varying the tubular structure with the interlock, the thickness of the sample could be controlled and reduced.

[19] Complete sample list in Appendix 2.6

Figure. 7.19 Spacer structure: PVDF yarns inlay between two cash-wool outer surfaces (Author's archive)

7.3.3.2 Sample thickness, yarn combination and arrangement

In general, thicker samples saw greater perceived levels of softness (Samples 46-49; 45; 59; Figure 7.23) with a range of thinner samples being exceptions to this (Samples 40; 51; 55A; 55B; 58). Tucking the PVDF at every other stitch was used to help reduce the overall thickness of the sample (from 0.99mm in Sample 59 to 0.83mm in Sample 58). This is seen to increase the roughness since loops of PVDF yarn protrude above the surface (Samples 58 and 59).

Softness was affected when the PVDF yarn broke, either due to stitch arrangement (Sample 60) or due to floating PVDF stitches (exaggerated by the use of Lycra in Sample 50, by tucking at every other stitch and increasing the tension in Sample 59). To avoid yarn breaks, the racking should take place on a tubular rather than an inlay row (Figure 7.20).

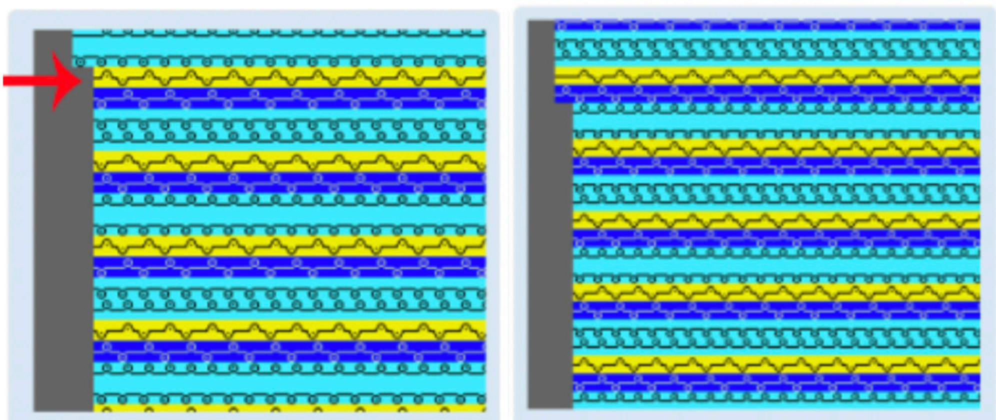


Figure. 7.20 Left: racking on an inlay row; Right: racking changed to a tubular row

Yarn arrangement is also a contributing factor to surface roughness. In Sample 51 the cotton-zinc and PVDF yarns are randomly oriented in the structure since they are simply knitted in. This can be controlled by employing a plating technique, as seen in Sample 52, generating a distinct difference in surface roughness between the 'right' and 'wrong' sides of the textile. In Sample 55, the placement of the Lycra notably influenced perceived softness. By knitting the Lycra with the cotton-zinc, (rather than with the PVDF in the spacer in Sample 54), softness levels increased. When looking at the influence of percentage stretch on levels of softness overall (Figure 7.24) the data demonstrates that, when integrating PVDF monofilament, the less stretch the greater the perceived level of softness.

Notably, softness types can differ in accordance with seasonal needs; e.g. smoother, less fibrous yarns were more desirable in warmer months, versus more fibrous yarns for winter. Levels of softness were also related to perceived level of luxury and quality of the textile/ garment. When asked, comfort was seen to be more closely associated with luxury goods and much less so with medical wear which were viewed as holding 'practical considerations' as priority. This level of familiarity in association of such qualities to medical devices in turn was seen to influence levels of trust towards the garment as a medical device and whether it would achieve the desired results of recovery; but also, compliance.

Body temperature requirements post-stroke are seen to influence the degree of softness and needs for maintaining a comfortable body temperature. Due to concerns raised in 'Series II' regarding body temperature requirements (in both hotter and cooler temperatures), a lighter layer is considered beneficial since it can either be worn on its own or layered with other garments. Technical investigations aim to reduce the overall thickness of the textile for this purpose.

Combining properties within a single yarn (Sample 58) by using a softer yarn with elastane properties reduces overall textile thickness, by reducing the need to use multiple yarns (Sample 57). This raises concerns for textile recycling at the garment's 'end-of-life'. The integration of PVDF yarns further adds to this complexity. Multiple yarns are considered to be easier to recycle than fibre-based methods of integrating nanofibers into existing yarns (e.g. PVDF nanofibers into cotton). The separation of materials can prove more difficult (Navone et al., 2020).

7.3.3.3 Tension

The level of tension varies according to the yarn combination used. Combining Lycra and PVDF in the inlay (Samples 54; 56; 57) increases surface roughness as the PVDF protrudes more so from the surface. This is increased further following steaming. Loosening the tension from 10.5 to 11.5 in Sample 57 increased sample thickness from 1.5 to 2mm respectively.

"Qualities which contribute towards softness and comfort are seen to directly impact the style of garment. Changes in yarn combinations, tensions were also seen to change the physical appearance of the textile; Samples 53 and 57 display a 'polo' appearance, Samples 54 and 55 a 'soft cardigan', whilst Samples 49 and 50 may be considered appropriate for use in compression socks or tight fitting sportswear" (Salisbury, n.d. [a]). A tighter tension contributes towards a 'stiffer' handle of the textile (e.g. Sample 56) and, in some cases, an increased stretch ratio (e.g. Sample 55).
The final sample used an interlock tubular spacer structure with yarn combinations of black lycra, PVDF and conductive yarn in order to achieve a lightweight, high-stretch, super soft jumper (Chapter nine).

SOFTN

1	2	3

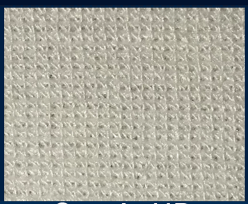
VERY ROUGH

Sample 43
PVDF, Cotton- zinc & lycra
1:1 rib
Thickness: 1.46mm
SURFACE SOFTNESS LEVEL: **1**

Sample 41
PVDF, Cotton- zinc & lycra
Half cardigan
Thickness: 1.4mm
SURFACE SOFTNESS LEVEL: **2**

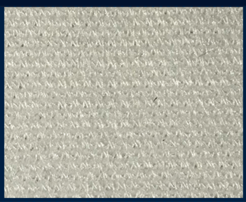
Sample 42
PVDF, Cotton- zinc & lycra
Cardigan
Thickness: 1.4mm
SURFACE SOFTNESS LEVEL: **2**

Sample 39
PVDF, Cotton- zinc & lycra
Half milano & mock rib
Thickness: 1.17mm
SURFACE SOFTNESS LEVEL: **3**



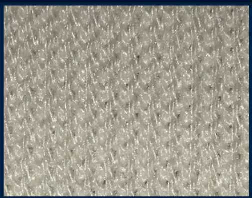
Sample 11D
Cotton-zinc (34); PVDF;
White lycra
Interlock spacer
Tension: 9.5, 8
Thickness: 1.09mm
SURFACE SOFTNESS LEVEL: **2**

Sample 11E
Cotton- zinc (20-1); PVDF;
White lycra
Interlock spacer
Tension: 9.5, 8
Thickness: 1.27mm
SURFACE SOFTNESS LEVEL: **2**



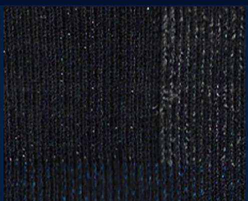
Sample 11F
Cotton- zinc (34); PVDF;
White lycra
Interlock spacer
Base tension: 9.5, 8
Thickness: 0.96mm
SURFACE SOFTNESS LEVEL: **2.5**

Sample 54 *[originally 11C]*
Cotton- zinc (34); PVDF;
White lycra
Interlock spacer
Tension: 9.5, 8
Thickness: 0.95mm
SURFACE SOFTNESS LEVEL: **2.5**



Sample 54 *[originally 11B]*
Cotton- zinc (20-1); PVDF;
White lycra
Interlock spacer
Tension: 10, 8
Thickness: 1.23mm
SURFACE SOFTNESS LEVEL: **2.5**

Sample 54 *[originally 11A]*
Cotton- zinc (20-1); PVDF;
White lycra
Interlock spacer
Tension: 11, 8.5
Thickness: 0.87mm
SURFACE SOFTNESS LEVEL: **2.5**



Sample 50 *[originally 4]*
Elastane; PVDF;
Grey and blue lycra
Tubular spacer
Base tension: 11, 8
Thickness: 1.44mm ±0.12
SURFACE SOFTNESS LEVEL: **3**

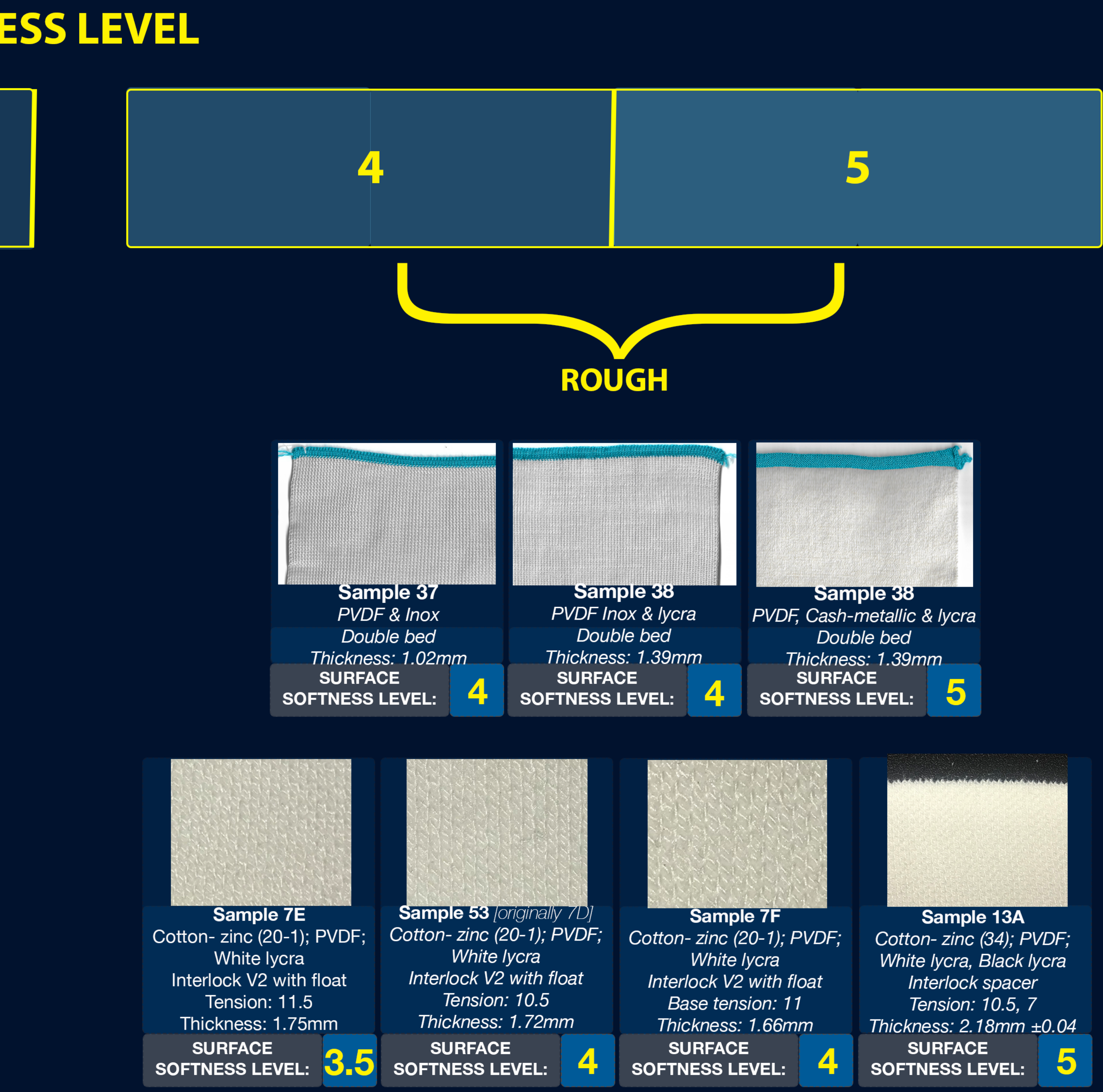
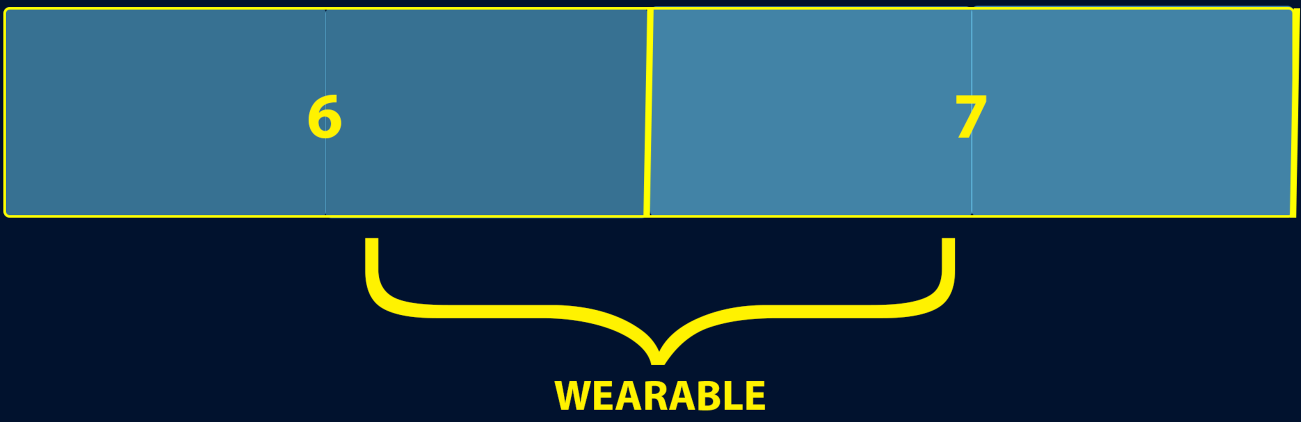


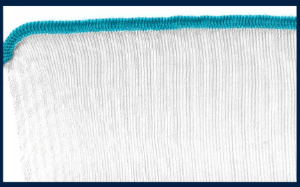
Figure. 7.21 Sample softness grading: 'Very Rough' to 'Rough' (Salisbury, n.d. [a])

SOFTN



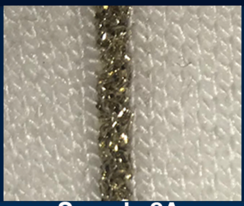
Sample 40
PVDF, Cotton- Zinc (ZTK 20-1)
Half milano & mock rib
Thickness: 0.59mm ±0.04

SURFACE SOFTNESS LEVEL: **6**



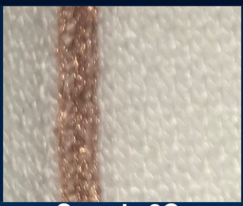
Sample 44
PVDF, Cotton- Zinc
PVDF spacer
Thickness: 0.62mm

SURFACE SOFTNESS LEVEL: **7**



Sample 8A
Cotton-zinc (ZTK 20-1);PVDF; White lycra; lurex [Interlock V2 with float]
Tension: 11
Thickness: 1.83mm

SURFACE SOFTNESS LEVEL: **5.5**

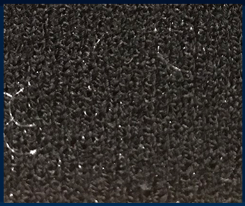


Sample 9C
Cotton-zinc(20-1);PVDF; white lycra; 20%Inox/ 80%PES Interlock with float
Tension: 11
Thickness: 1.73mm

SURFACE SOFTNESS LEVEL: **5.5**

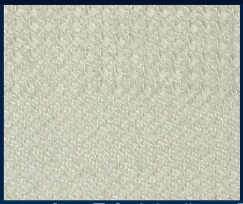
Sample 58 *[originally 13B]*
Black lycra; PVDF
Interlock spacer
Tension: 10.5, 10.5, 7
Thickness: 0.83mm

SURFACE SOFTNESS LEVEL: **6**



Sample 60 *[originally 14B]*
Black lycra; PVDF
Interlock spacer
Tension: 10, 11, 8
Thickness: 0.85mm

SURFACE SOFTNESS LEVEL: **6**



Sample 57 *[originally 12B]*
Cotton- Zinc (34); PVDF; White lycra
Interlock spacer
Tension: 10.5, 8 to 11.5, 8
Thickness: 1.83mm

SURFACE SOFTNESS LEVEL: **6**

Sample 56 *[originally 12A]*
Cotton- Zinc (34); PVDF; White lycra
Interlock spacer
Base tension: 9.5, 9.5, 8
Thickness: 1.78mm

SURFACE SOFTNESS LEVEL: **6**

Sample 52 *[originally 7B]*
Cotton- Zinc (ZTK 20-1); PVDF; White lycra
Interlock and tubular
Tension: 10
Thickness: 1.72mm

SURFACE SOFTNESS LEVEL: **6**

Sample 7C
Cotton- Zinc (ZTK 20/1); PVDF; White lycra
Interlock V2 with float
Tension: 9.5
Thickness: 1.64mm

SURFACE SOFTNESS LEVEL: **6**

Sample 7A
Cotton- Zinc (ZTK 20/1); PVDF
Interlock and tubular
Tension: 9.5
Thickness: 0.97mm

SURFACE SOFTNESS LEVEL: **6.5**

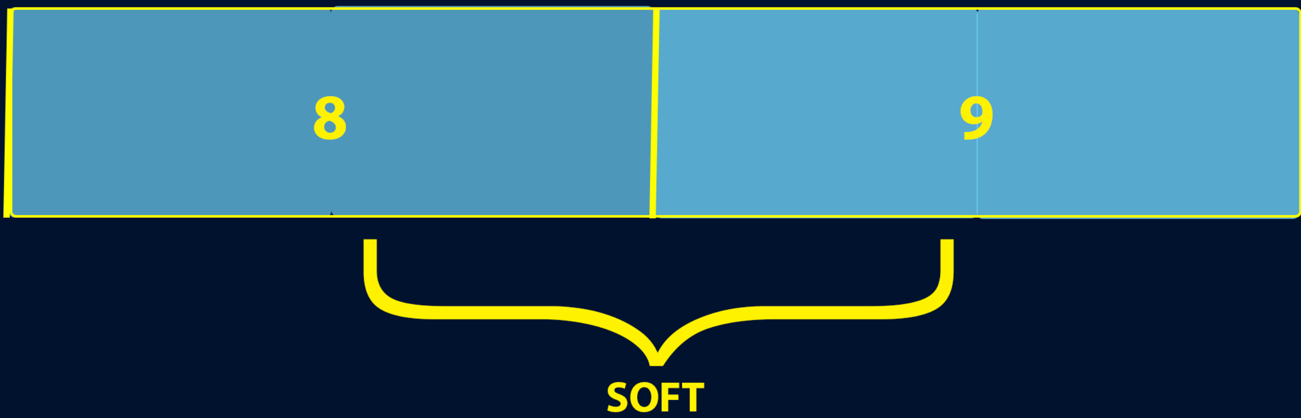
Sample 14F
Replacement; PVDF
Interlock spacer
Tension: 11, 10, 7
Thickness: 1.43mm

SURFACE SOFTNESS LEVEL: **6.5**

Sample 55 *[originally 11G]*
Cotton- Zinc (ZTK 20/1); PVDF; White lycra
Interlock spacer
Tension: 9.5 & 10.5
Thickness: 0.94mm ±0.2

SURFACE SOFTNESS LEVEL: **6.5**

ESS LEVEL



Sample 45
PVDF; Cash-wool
Spacer
Thickness: 1.81mm

SURFACE SOFTNESS LEVEL: **8**

Sample 48
Nylon monofilament;
Cash-wool; lycra (white)
Spacer
Thickness: 1.56mm

SURFACE SOFTNESS LEVEL: **9**

Sample 47
Nylon monofilament;
Cash-wool; lycra (white)
Spacer
Thickness: 1.59mm

SURFACE SOFTNESS LEVEL: **9**

Sample 46
Nylon monofilament;
Cash-wool; lycra (white)
Spacer
Thickness: 0.83mm
(1 end of wool not 2)

SURFACE SOFTNESS LEVEL: **9**

Sample 51 *[originally 6B]*
Cotton-zinc (20-1); PVDF
Full interlock
Tension: 9.5
Thickness: 0.74mm

SURFACE SOFTNESS LEVEL: **8**

Sample 1
Cotton-zinc(20-1&34);PVDF;
Grey and blue lycra
Tubular spacer
Tension: 12, 9
Thickness: 0.95mm ±0.09

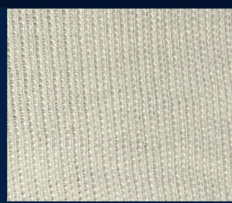
SURFACE SOFTNESS LEVEL: **8**

Sample 14D
Black lycra; PVDF
Interlock spacer
Tension: 10, 11, 7
Thickness: 1.04mm

SURFACE SOFTNESS LEVEL: **9**

Sample 14E
Black lycra; PVDF
Interlock spacer
Tension: 11, 10, 7
Thickness: 1.04mm

SURFACE SOFTNESS LEVEL: **9**



Sample 6A
Cotton- Zinc ZTK 20/1
Full interlock
Tension: 9.5
Thickness: 0.48mm

SURFACE SOFTNESS LEVEL: **9**

Sample 49 *[originally 2]*
Cotton-zinc(20-1
&34);PVDF; White, grey and
blue lycra; Tubular spacer
Tension: 12, 9
Thickness: 2.14mm ±0.1

SURFACE SOFTNESS LEVEL: **9**

Sample 3
Cotton-zinc(20-1
&34);PVDF; White, grey and
blue lycra; Tubular spacer
Tension: 11, 8
Thickness: 1.8mm ±0.07

SURFACE SOFTNESS LEVEL: **9**

Sample 59 *[originally 14A]*
Black lycra; PVDF;
20% Inox/ 80% PES
Interlock spacer
Base tension: 10, 11, 8
Thickness: 0.99mm

SURFACE SOFTNESS LEVEL: **9**

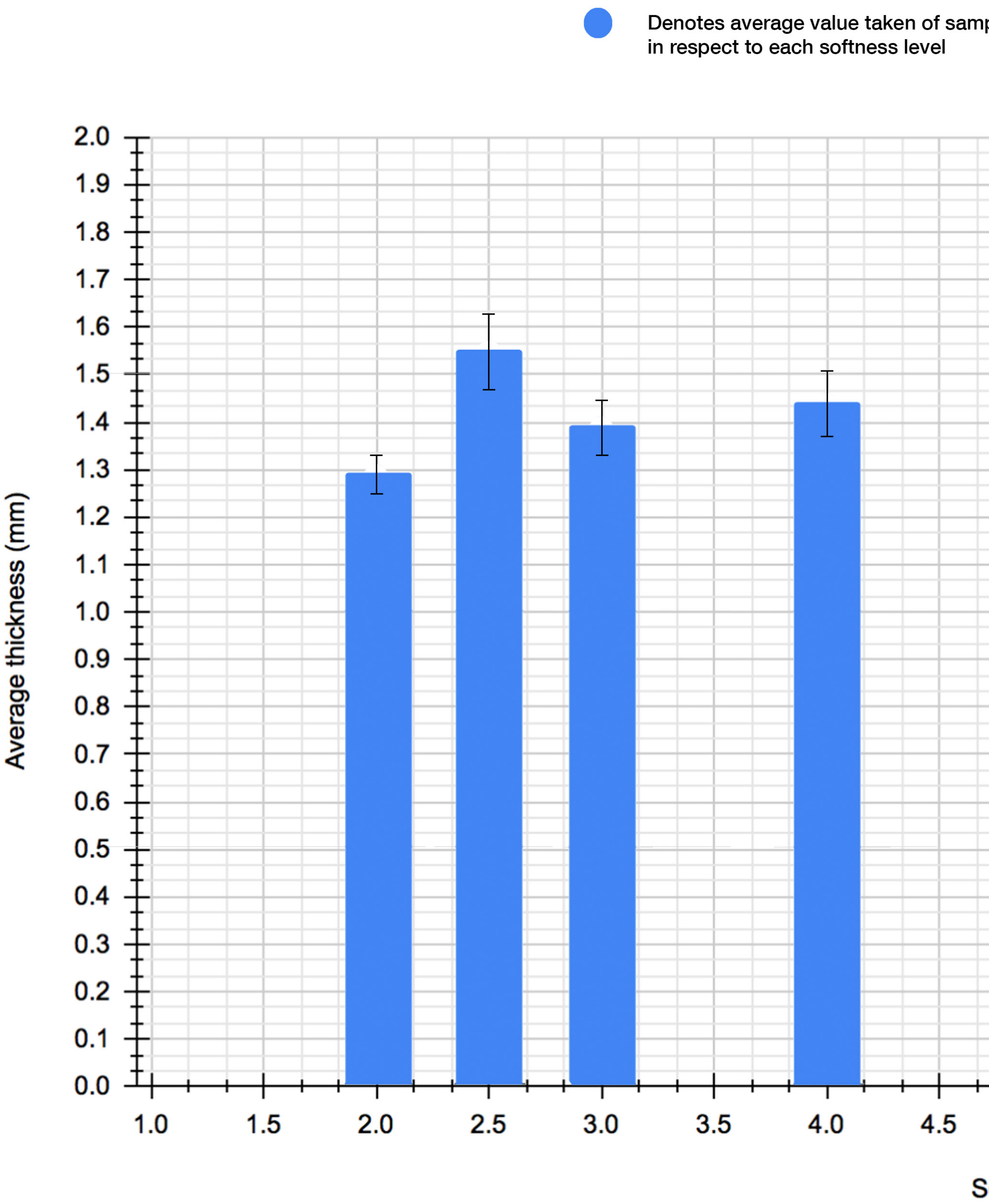
SLV 4
Black lycra; PVDF;
20% Inox/ 80% PES
Interlock spacer
Base tension: 11, 10, 7
Thickness: 1.43mm

SURFACE SOFTNESS LEVEL: **9**

Sample 5
Cotton- Zinc (ZTK 20/1)
Partial interlock
Tension: 9.5 & 10
Thickness: 0.42mm

SURFACE SOFTNESS LEVEL: **9**

Figure. 7.22 Sample softness grading chart: 'Wearable' to 'Soft'(Salisbury, n.d. [a])


Denotes average value taken of samp
in respect to each softness level
Average thickness (mm)
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
S

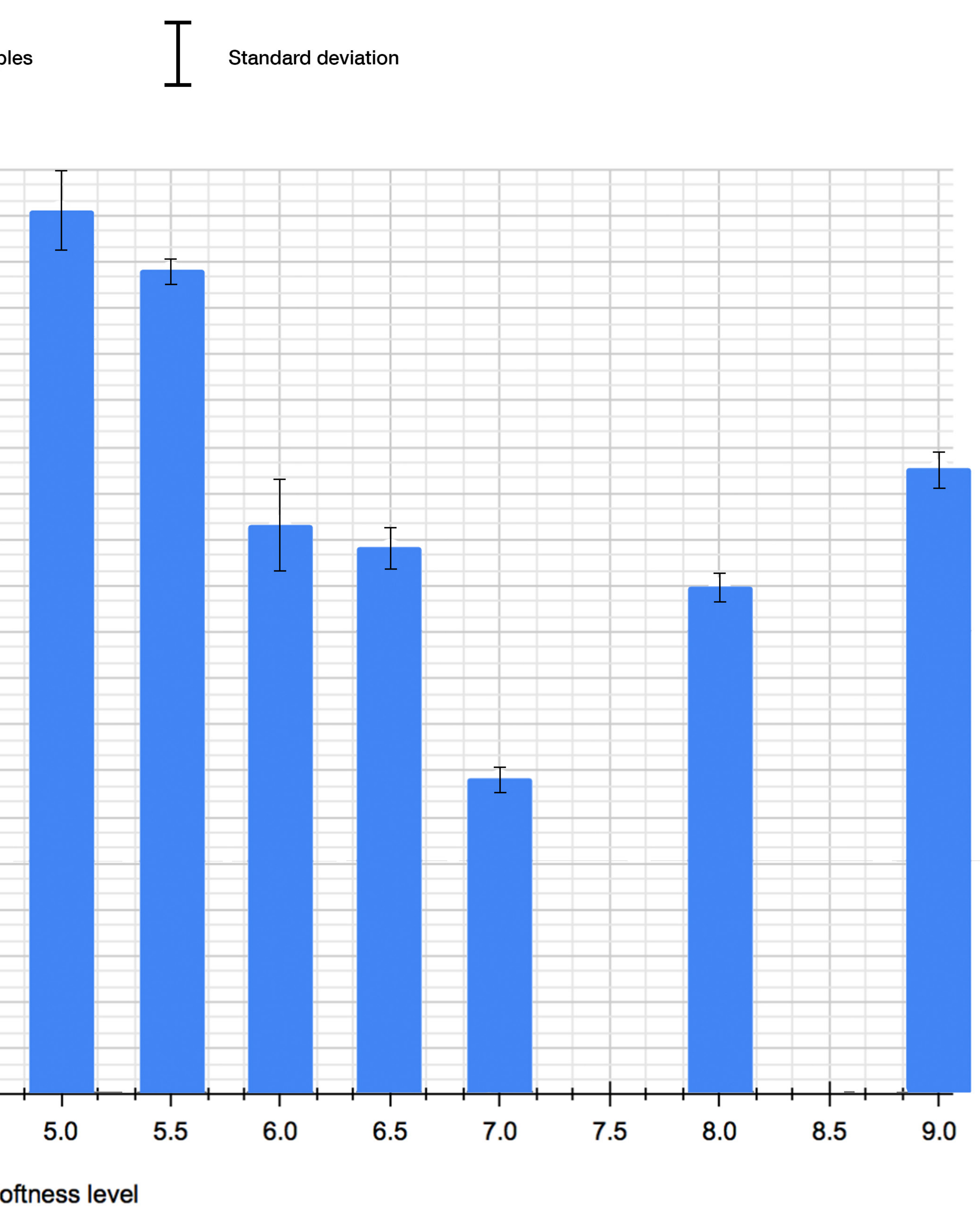
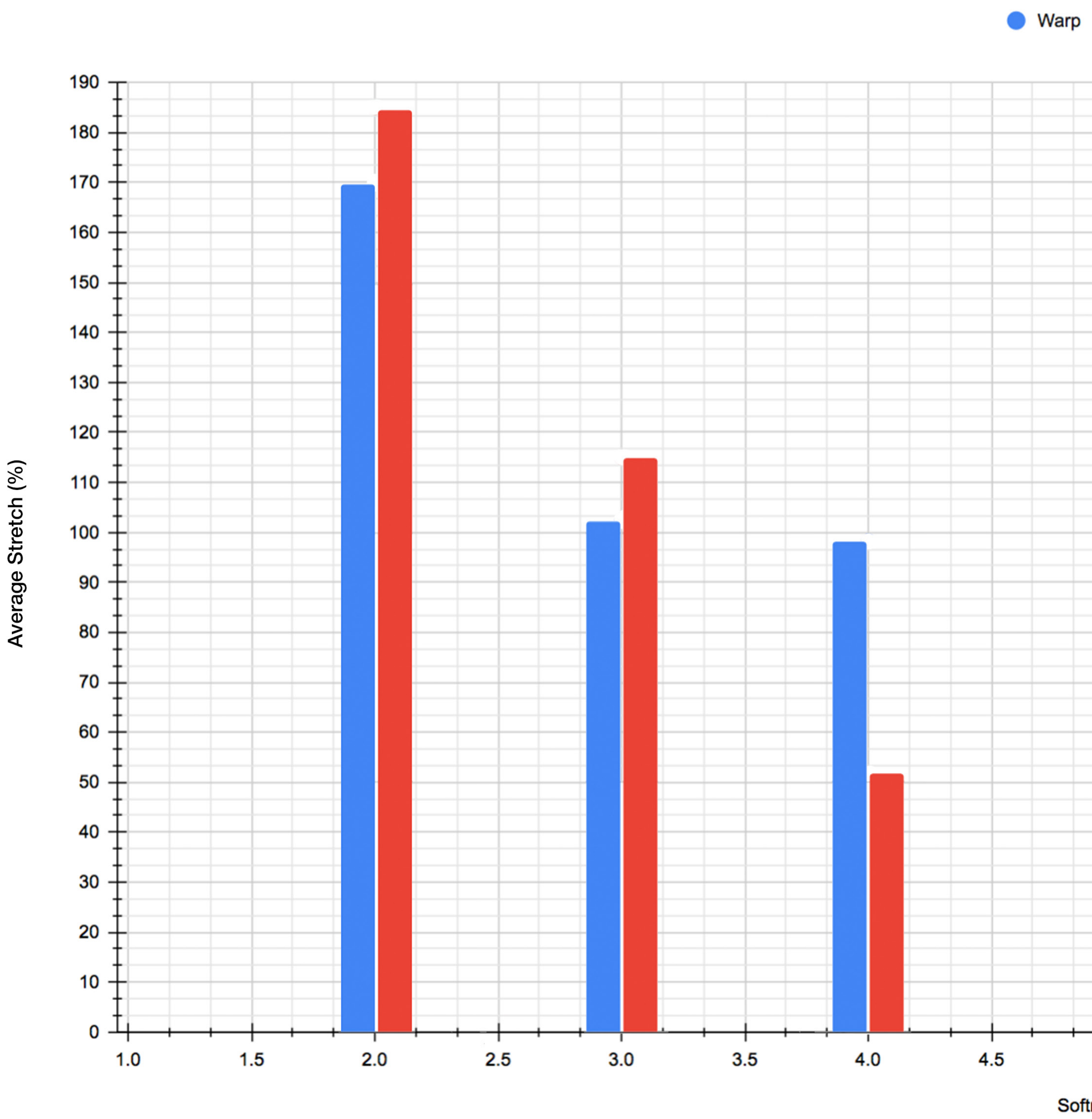


Figure. 7.23 Average thickness per softness level (Salisbury, n.d. [a])



Warp
Average Stretch (%)
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5

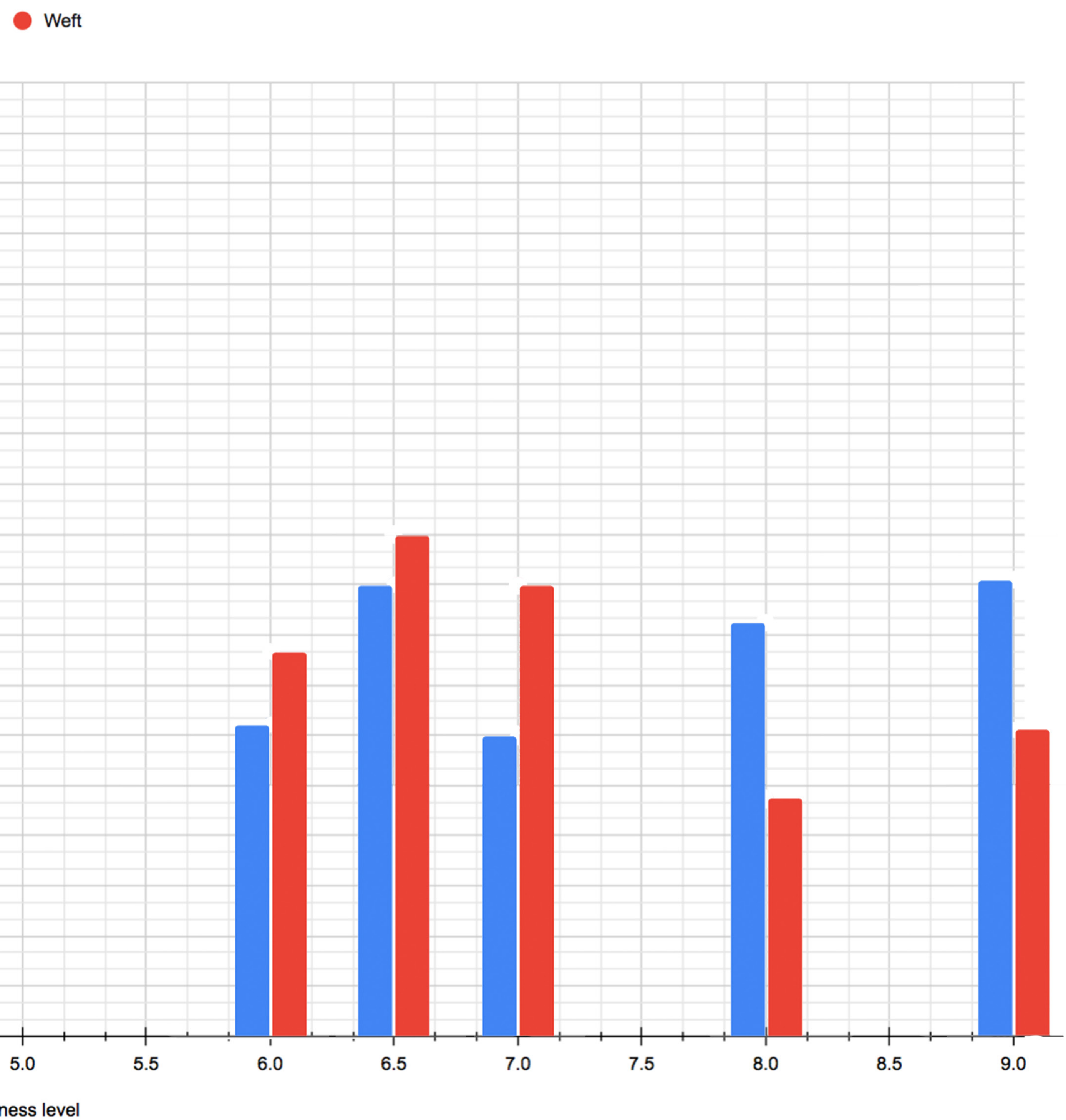


Figure. 7.24 Average percentage (%) stretch per softness level (Salisbury, n.d. [a])

7.4 Chapter 7.0 summary

Due to the increase in studies exploring the technical capacity and output performance of energy harvesting yarns, there exists a real need to understand how energy harvesting yarns may be integrated into wearable garments. In particular, how the tactile experience, particularly in terms of 'softness' can be manipulated.

The act of wearing clothing generates tactile sensations that can elicit pleasant or unpleasant responses. Of the most irritating sensations from wearing clothing, a 'fabric-evoked prickle' is rated as being the worst (Li and Wong, 2006). Associations with feelings of being uncomfortable when wearing a textile that is 'prickly' (Garnsworthy et al., 1988b; Smith, 1987) can be identified as triggering pain nerve endings from a threshold of 0.74mN (Garnsworthy et al., 1988a). Within this study, samples which ranked worst were those where the PVDF yarn floated above the surface, protruding out, producing a rough surface. Small pieces of broken PVDF yarn (Figure 7.18), were caused by issues during the shaping process where the racking starts on a row of tucked stitches (Figure 7.20).

Within Chapter six, the use of rubbery matrices were discussed in regards to their use within the development of flexible energy harvesting materials (Chou et al., 2018). A final note is made towards this particular process. Where larger pieces of rubbery matrices may not be most suited for integration into garments, a reconsideration into how the use of silicones are used may present a better opportunity. Interestingly, the use of silicone is frequently used to create fabric softeners, specifically for wools, in order to increase fiber flexibility; specifically bend and twist (Naebe et al., 2013). Similarly to methods used for carbonising cotton yarns and other methods for energy storage (Mirvakili et al., 2015), considerations may turn towards the exploration of impregnated fabrics with PZT/silicone nanofibers (or alternatives to PZT) that simultaneously soften whilst embedding functionality may be a desirable route to integration.

Furthermore, the concept of the 'familiar', 'typical', 'usual' or 'expected' elements of a textile that contribute towards a sense of a 'norm' (as expressed in Chapters two and three) is an element that can be seen to determine the acceptance and use of wearable technology (Salisbury, Ozden-Yenigun and McGinley, n.d). Yet, when it comes to trusting a textile to deliver 'treatment', a 'familiar' garment can generate a level of scepticism and mistrust: *"can a textile do that?!"* (CE, 2019) is a typical response.

In reference to key challenges raised in Section 3.2.4 in Chapter three, this Chapter has demonstrated that the textile can be constructed in a manner that resists obscuring the familiar appeal of garments when integrating e-textiles functions, specifically energy harvesting methods for powering e-textile components.

Overall, spacer structures have been highlighted in Chapter six as being suitable textile structures for integrating piezoelectric 'components' (Liu et al., 2016; Kwak et al., 2017), but also within this Chapter due to their suitably 'soft' qualities. As this chapter has demonstrated, the spacer structure needs considering to be deemed suitable for wear in particular seasons and garment styles. Yet, the structure provides the opportunity to consider the placement of the 'bead' between the surfaces (Figures 7.20 and 7.25) and therefore surrounded by energy harvesting yarns (an alternative approach to self-powering the device where fatgue can reduce the level of engagement).

[The following figure that appeared in the thesis was redacted due to its commercially sensitive nature.
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Figure. 7.25 Working hypothesis: A diagrammatic representation of bead placement

Depending on yarn combination, spacers were noted by participants as being too thick (Samples 45 - 48) or delicate (Sample 44). The investigations in Sample Series III have demonstrated that the level of softness can be manipulated during the sampling process (Figures 7.22 to 7.24). However, the PVDF yarn used is a monofilament constructed via melt-spinning. Alternative methods of constructing a piezoelectric PVDF yarn (explored in Chapter eight) may also yield different responses to the parameters used.

This can raise further challenges and issues beyond the immediate use of the garment as a therapeutic intervention. Namely, when reflecting back on Chapters two and three, the impact of 'concealing' a component or device related to disability. This can have a knock-on effect on the visability of disability in society which can present issues of acceptance and inclusion.

Beyond this, further key challenges emerge from using yarn-based energy harvesting methods. This includes:

1. The need for energy storage suited to power requirements of the textile components;
2. A need for methods of powering the device if energy harvesting methods do not fulfill this. This may be in combination with energy harvesting methods or as an alternative. Where it is not in the scope of this thesis to explore this, it should be noted that considerations for cost and influence on behaviour of use and compliance should be acknowledged when making this decision.
3. Methods for controlling and connecting the textile components.

The focus of this chapter has not been on the performance of the energy harvesting yarn but on the opportunities for integrating the yarn within the textile in a manner that complements expectations of wear by the particapant groups.
Findings demonstrate how methods of grading participant responses can be particularly useful in developing materials in environments where participants have limited access. The iterative nature of making can be stifled by stopping and starting to go away and collect feedback all too frequently.

Where it is not in the scope of the thesis to explore all of these challenges, they will form part of future work. However, Chapter eight will embark upon evaluating the performance of a yarn specimen to be able to evaluate the role of energy harvesting in powering the device.

CHAPTER

8.0

Yarn design, construction, experimentation and testing

8.1 Chapter 8.0 Overview

Chapter eight builds on findings from Chapters six and seven, presenting a theoretical exploration of yarn compositions for a yarn-based energy harvester. A focus is placed on the functional performance of one of the proposed concepts (Concept one) via a range of experimentation (electrospinning) and material characterisation techniques (DSC, XRD and piezo response testing using an oscilloscope and Instron tensile tester).

In evaluating the functional performance of the yarn specimens the chapter begins to evaluate the potential role of energy harvesting in the device. In particular, it seeks to understand to what extent the yarn specimens may contribute to powering the device.

It should be noted, however, that due to limitations in access to equipment, the research was unable to explore the optimum yarn concept (twelve). This remains part of future work. However, the specimen that was sampled, thanks to a partnership with PhD student Alrai at Istanbul Technical Universtiy, provides an evaluation to the use of energy harvesting methods could be explored alongside the literature referenced in the chapter.

Section 8.2 begins by reviewing yarn composition and its ability to influence the functional performance of the application to harvest energy and deliver stimuli, bearing the intended use. Where a detailed summary of each concept is provided in Appendix 2.8, this Chapter will embark on a range of initial investigations (Sections 8.3 and 8.4).

Yarn construction and experimentation 8.2

8.2.1 Yarn concepts: Overview

Textile composite 'components' are increasingly attractive for use in many modern industries as a result of their excellent mechanical properties; fatigue strength, 'high specific stiffness and strength', dimensional stability and excellent corrosion resistance (Soutis, 2005). However, depending on their composition[1], textile composites can be prone to varying modes of failure including delamination, cracks and fibre breaks (Thierry et al., 2018) as well as variations in output performance.

[1] E.g. if laminated and reinforced with continuous medium (Figure 8.58)

Figure 8.1 provides an overview of yarn concepts developed in response to earlier experiments and an
alternative approaches to electrospinning and theoretical potential above concepts two to eleven, justifi
conductive yarn substrate, whilst Concept twelve spins and twists a complete nanofiber yarn.

It is hypothesised that Concept twelve will have a greater output performance than Concept one due to p
the core conductive yarn. Concept one has been sampled and tested, whereas Concept twelve, a hypo
Concepts two to eleven (included in Appendix 2.8) demonstrate wider considerations for alternative yarn
these were not sampled.

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alysis (Chapters six and seven). A focus is placed on concepts one and twelve since they present key
ied in Section 6.3 (Chapter six) and Appendix 2.8). Concept one spins nanofibers directly onto the core

predicted issues concerning the mechanical stability and interfacial bonding between the nanofibers and
thesis developed as a result of experimental findings, remains theoretical and has yet to be sampled.
designs that informed and were informed by concepts one and twelve. However, due to time constraints

[redacted]

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bury@rca.ac.uk].

Figure. 8.1 A summary of considered yarn structures: Concepts 1-12

8.2.2 Concept 1: Limitations and considerations

In Concept one the yarn is composed of a core conductive yarn that acts as an electrode to extract charge from the PVDF nanofibers and a substrate which the PVDF is electrospun[2] directly onto. The PVDF and PVB layers provide insulation (Almusallam et al., 2013) as well as acting as piezoelectric and encapsulation materials, respectively. The mechanical stability of the nanofiber layer is dependent on the characteristics and surface quality of the core yarn. The material rigidity difference between conductive 'wires'[3] and the piezo material has, in previous studies, caused poor mechanical coupling between the nanowire and piezoelectric material. Poor interfacial bonding can result in device damage after several stretch and release motions (Xu and Zhu, 2012; Yu et al., 2015; Park et al., 2017) and since the electrode requires excellent mechanical compliance to support optimum output performance, this is an issue.

Conductive particles (e.g. Ag particles[4]) may be used as an alternative to wires to reduce the resistivity of the polymer phase into the composite (Sancaktar and Bai, 2011), which in turn increases the effective electric field on the piezoelectric particles.

An insulation layer is typically applied to protect the electrode from damage or contamination. A dip-coated PVB encapsulation layer enables the yarn to withstand everyday wear and manufacturing processes. The method for coating the yarn should avoid tedious steps that could limit the production of continuous yarns as well as the consideration for the use of solvents since this could react with the PVDF nanofibers.

The overall yarn diameter should be suitable to the knit process and garment type. A finer yarn is considered more beneficial since this can be twisted together (Park et al., 2019) to construct heavier textiles or used in a single ply for lighter textile structures. The dtex of the core yarn should be sufficient to act as a substrate for the application of PVDF whilst not compromising the overall yarn dtex.

8.2.3 Concept 12: Limitations and considerations

[The following text that appeared in the thesis was redacted due to its commercially sensitive nature.
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[2] "Electrospinning is a versatile method of producing continuous nanofibres through the application of an electric field" (Salehhudin et al., 2017). However, the process is typically time consuming and presents limitations to scaling up applications.
[3] Studies using nanowires (Hecht et al., 2011; Kumar and Zhou, 2010) typically use a restricted length of 1-20μm (Lee et al., 2012) and display relatively weak electrical and mechanical properties.
[4] Adding Ag nanoparticles to a polymer piezoelectric matrix improves dielectric constant (d33) by 18%, but decreases peak output voltage (Almusallam et al., 2017). A maximum d33 value of 43.5 pC/N was reached at 0.2wt% of Ag; an 8% increase compared to the composite without Ag.
[5] Applying 13kV after heating the PVDF to 80°C during the melt extrusion process.
[6] Appendix 2.4

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Technical investigations 8.3

A systematic approach was taken towards the developments to better understand the nature of the piezo yarn. Experimental Series I and II tests the application of PVDF to a conductive core yarn via electrospinning, with Series II further investigating the influence of spin time on coating thickness, uniformity and output performance.

A total of five months of this thesis' work was spent on Experimental Series I and Series II testing and sampling. Later phase tests, incorporating silver particles, encapsulation layers and use of PVDF-TrFE, are anticipated in post doctoral study (Figure 8.2).

[7] Used mainly for specialist purposes, e.g. filtration systems (Chen, 2011), fishing line, toothbrush bristles (Hagewood, 2014) and in the production of rope and twine (Ebnesajjad, 2015).
[8] From 2μA and 3.8V to 4.5μA and 7.9A; enough to power an LED for more than 30 seconds when a 33μF capacitor is charged by the PENG sample (via finger movements) to 6.5V (Abolhasani et al., 2017).

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Figure. 8.2 A systematic approach to yarn investigations

8.3.1 Methods: Experimental Series I and II

PVDF Solef-1008 and PVDF Sigma-275,000 mw, used without any modifications, were spun coated onto two types of conductive yarns (100% Inox and 97% Inox, 3% Cu) via electrospinning (Y Flow Nanotechnology Solutions); using Acetone and Dimethylformamide (DMF) as solvents. The electrospinning set featured a disposable syringe, a flat tip needle with a diameter of 8 mm, a high power voltage supply and a conductive collector plate with dimensions of 13 cm x 17 cm.

The samples were held in place by winding the yarn around fixed plastic stakes in a polystyrene frame (Figure 8.3). In order to ensure full coating the yarns were held in two different stationary positions directly below the spinneret by rotating the sample in the polystyrene frame.

In Series I seven different specimens were produced (Table 8.4), interchanging the yarn from steel-100% to steel-97%/ copper-3%. The PVDF material source, coating layer thickness, electric voltage output, and the Inox substrate were varied for a wider understanding of these changes on utilising PVDF nanofibers for energy harvesting applications. In Experimental Series II, the spin time was extended.

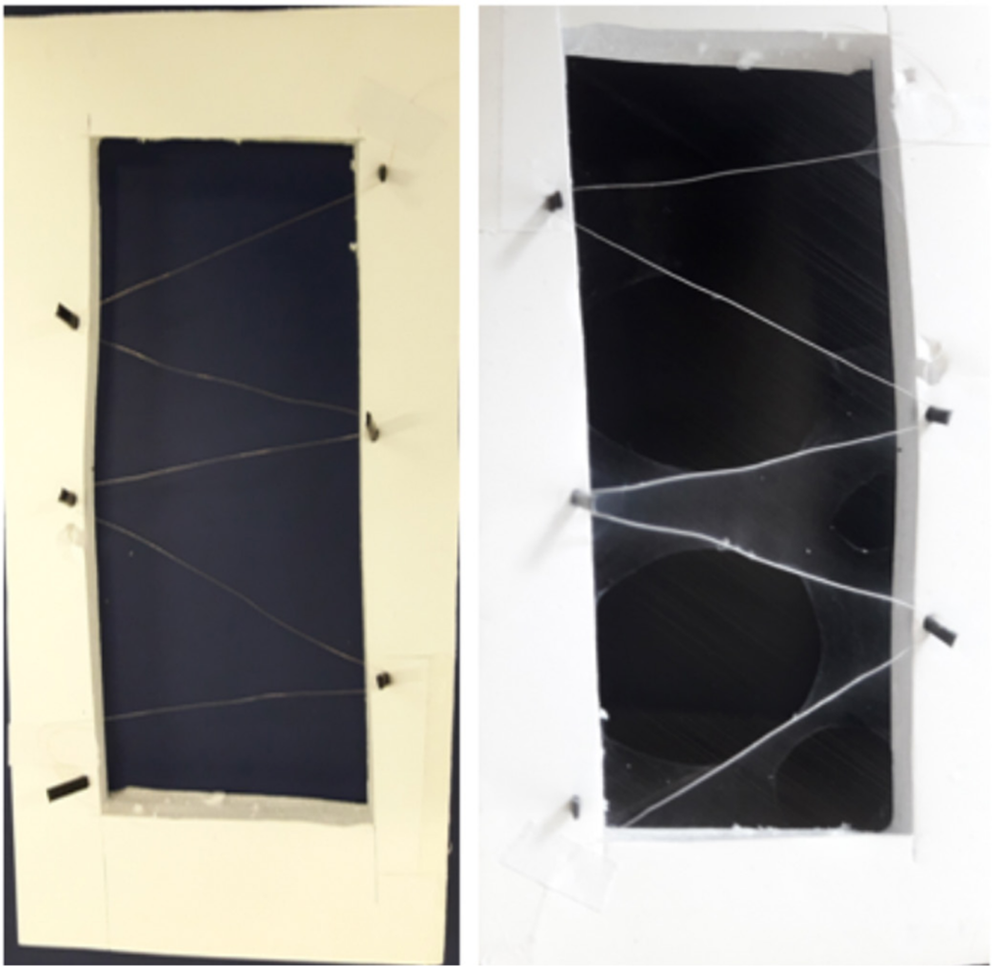


Figure 8.3 Photographic images of Specimen Si1. Left: Steel-97% & copper-3% (%vol) yarn before coating; Right: After NFs PVDF coating

Table 8.4: Summary of the specimens and their corresponding parameters

Specimen code[9]	Yarn	PVDF concentration *(wt.%)*	Electric voltage *(kV)*	Flow rate *(mL/h)*	Deposition time *(mins)*	Ambient temperature *(˚C)*	Humidity *(%)*
Si1	Steel 97% & copper 3%	15	6	0.5	5	~20	38
Si2	Steel 100%		5.8		9		
Si3			10		6		
So4			4.8				
So5	Steel 97% & copper 3%		7.5				
So6			17.1		20		
Si7	Steel 100%		7.7		15		
So8	Steel 97% & copper 3%		17	1	~35		
So9		18			~5		
Si10		15		0.5	~20	~23	36
Si11			11	1	~8		
Si12					~23		
Si13		18		0.7	~20		
Si14		15	6	1	>5	-	
Si15	Steel 100%		5.8		>9		
Si16			10	0.7	>6		
Si17		17	7.7		>15		
Si18	Steel 97% & copper 3%	18	11		5	~23	36
Si19					10[10]		
Si20					15		
Si21					25		

[9] 'So' in So1 refers to Solef-based solution; 'Si' refers to Sigma-based solution.
[10] This specimen did not have a good polymer jet causing difficulty in making an accurate conclusion on the effect of time deposition on the coated yarn.

8.3.2 Findings: Experimental Series I

1) The nanofibers exhibit poor interfacial bonding and stability to the core yarn. They are easily brushed off with a sweep of a finger and therefore highly unstable.

2) The electric voltage employed was the minimum that facilitated a stable polymer jet and Tylor cone for Specimens Si1, Si2 and So4. A minimum voltage[11] is typically required to overcome the surface tension of the solution droplet. Increasing the voltage increases the surface tension and viscosity but is also seen in some cases to reduce the diameter of nanofibers (Rodoplu et al., 2012; Heikkilä et al., 2007); the higher electric voltage outputs showed some instability in the formation of the polymer jet and Tylor cone. Nonetheless, all yarns were coated successfully, albeit somewhat lightly in several cases (Specimens So5, So4 and Si2).

3) Fibre diameter (Table 8.11) increased by 3-6 fold after coating (Figures 8.5 to 8.8), ranging from around 160 to 300 µm. This indicates that the yarn was not coated uniformly along the yarn.

4) Large amounts of 'waste' product (Figure 8.9) were observed since the spinning process could not be accurately controlled to only coat the yarn. It is considered that the process could be adapted in order to achieve this. This may include charging the yarn to attract the nanofibers towards the yarn; depending on the charge characteristics of the nanofibers.

5) The 'zig zag' formation of the yarn in the polystyrene frame (Figure 8.10) resulted in an interconnecting 'web'/ nanofiber membrane being formed at the innermost corners (Points i-v). The positioning of the yarn therefore requires reconsidering.

6) Due to the set-up, the range of the lengths of the coated yarns is limited (between ~30 – 80 mm). Therefore this method is not suitable for coating continuous lengths of yarn. One option may be to create a motorised yarn spool mechanism to pull the yarn through whilst simultaneously rotating it in order to obtain a more uniform coating. However, the delicate nature of the nanofiber's mechanical stability on the core yarn may restrict this whilst the set-up would continue to produce excess 'waste' nanofibers.

[11] ~4 kV (Salehhudin et al., 2017).

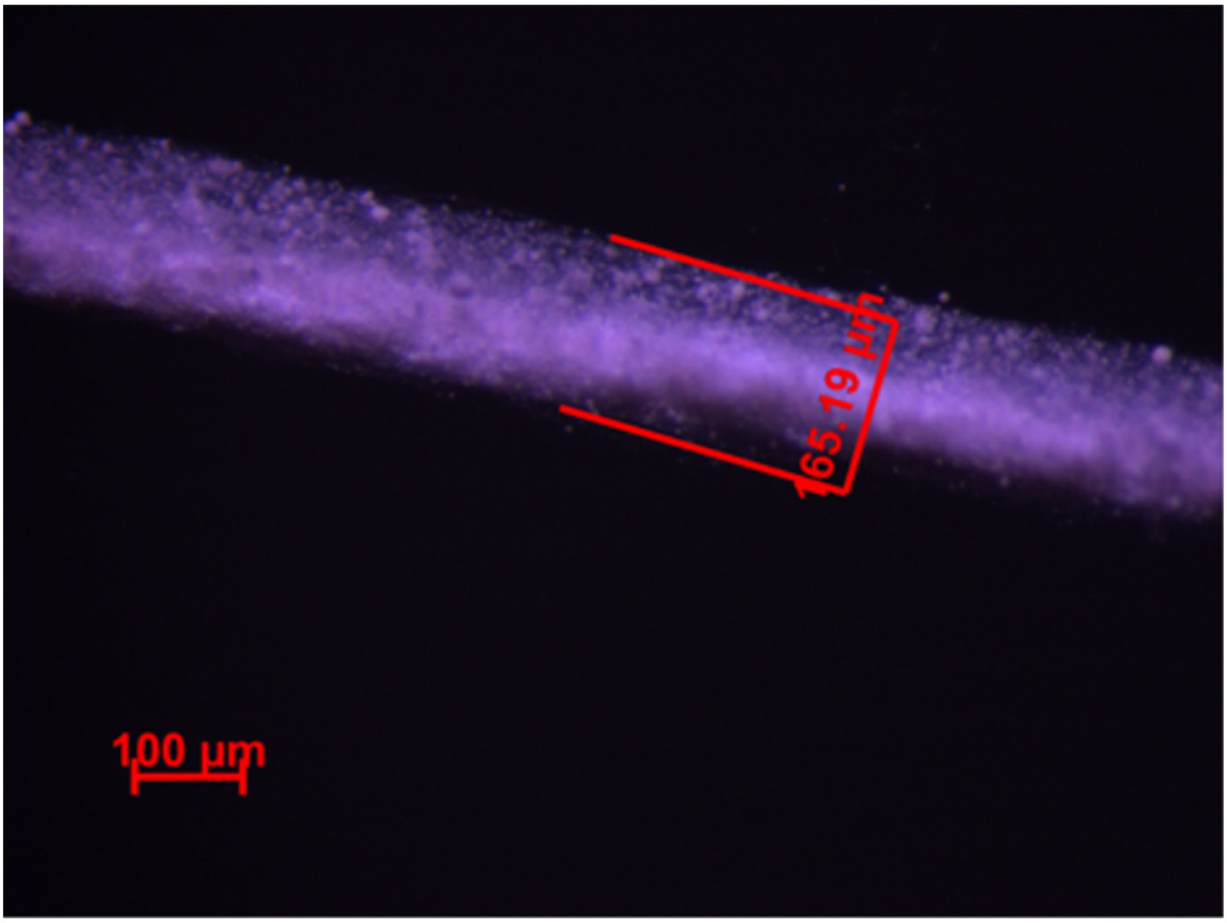


Figure 8.5 SEM image of So6.

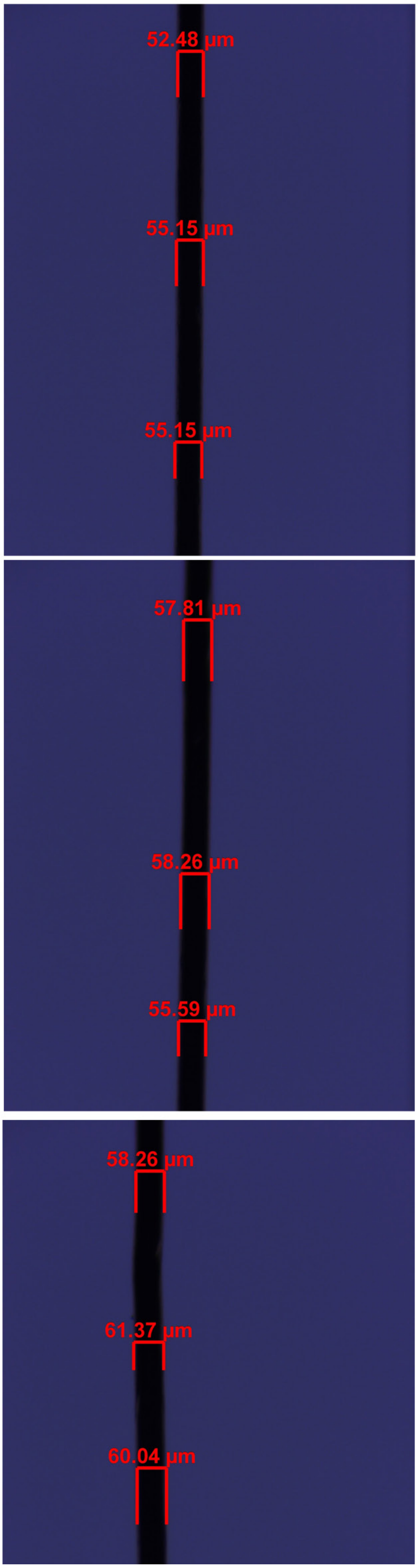


Figure. 8.6 SEM image of conductive yarns (100% steel) before coating

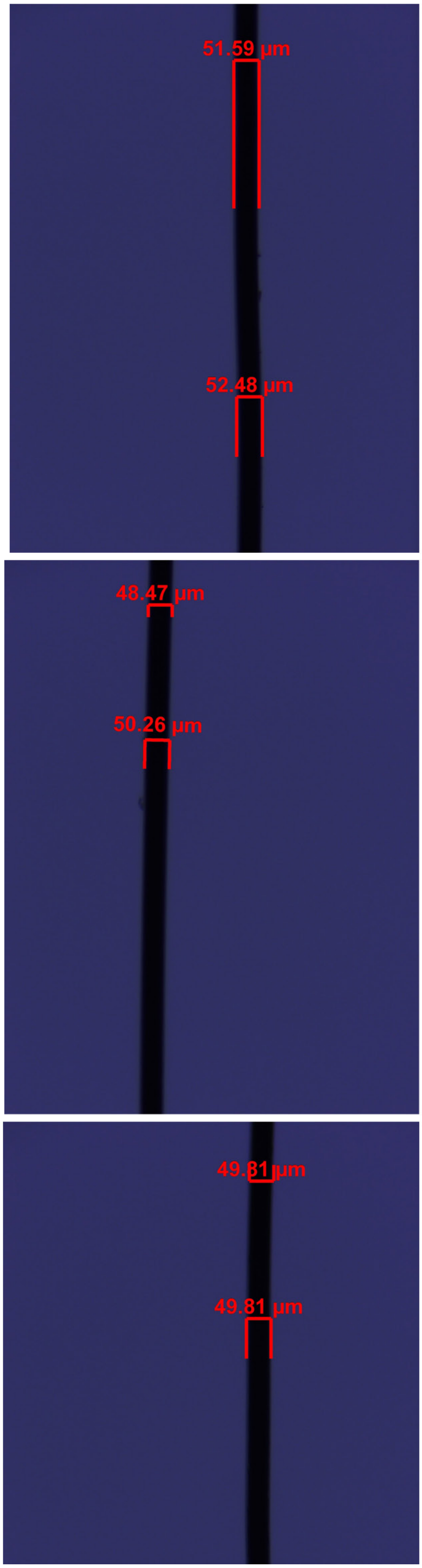


Figure. 8.7 SEM image of conductive yarns (97% steel, 3% copper) before coating

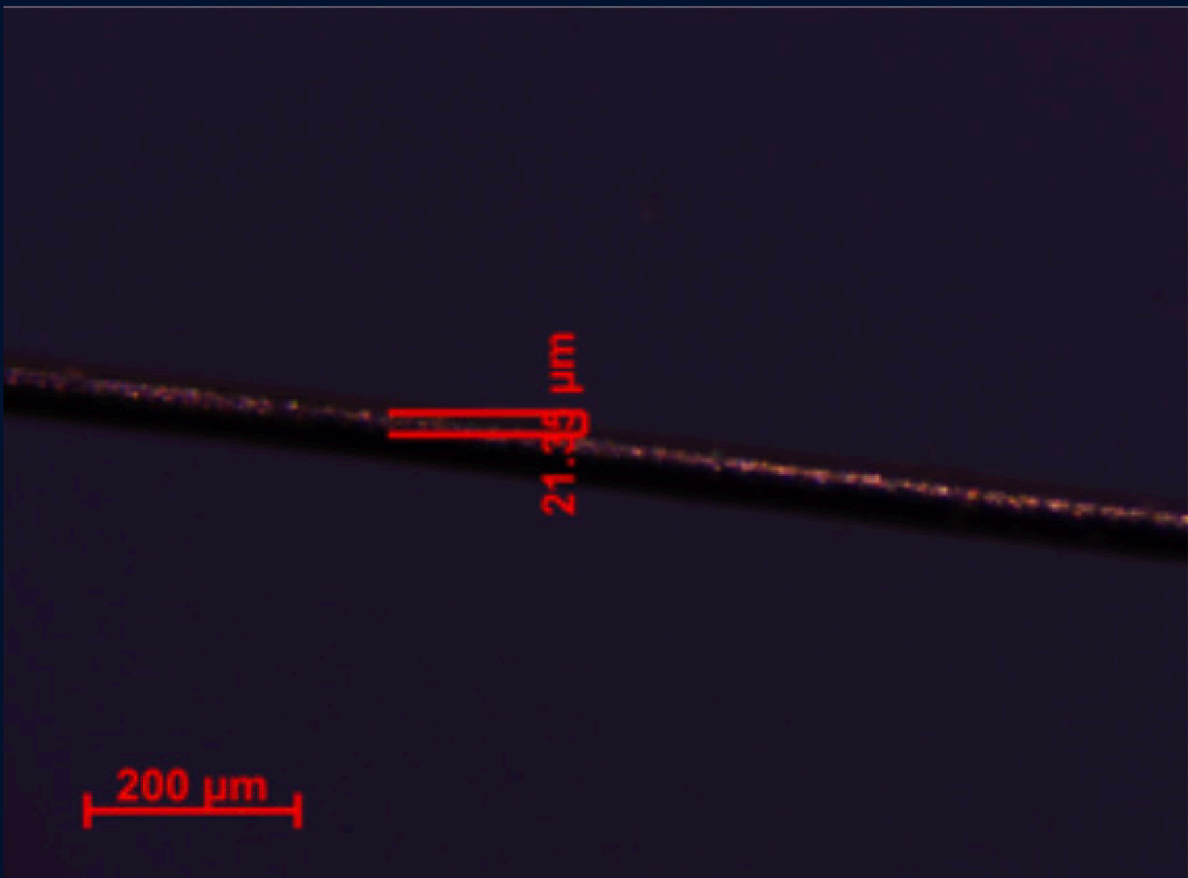


Figure. 8.8 SEM image of conductive yarns (97% steel, 3% copper) before coating: Close-up

Figure. 8.9 Excess nanofiber deposits

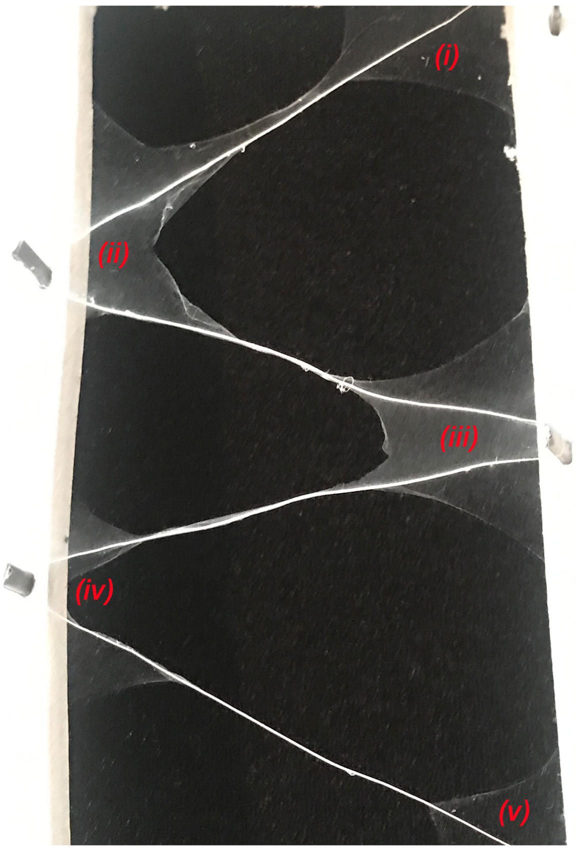
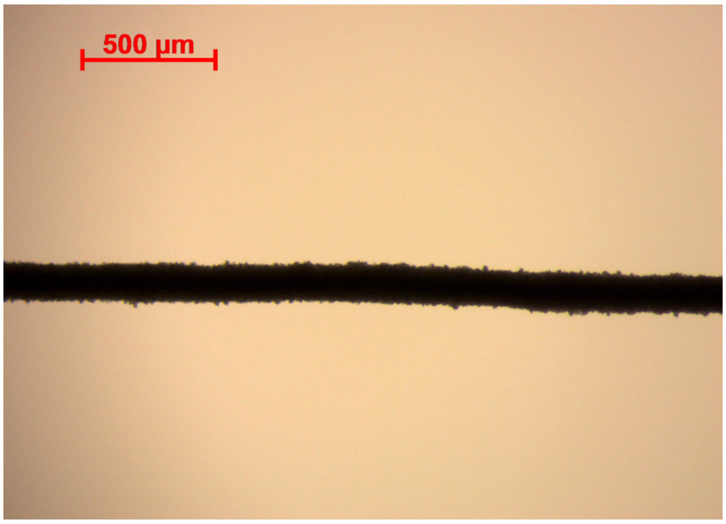


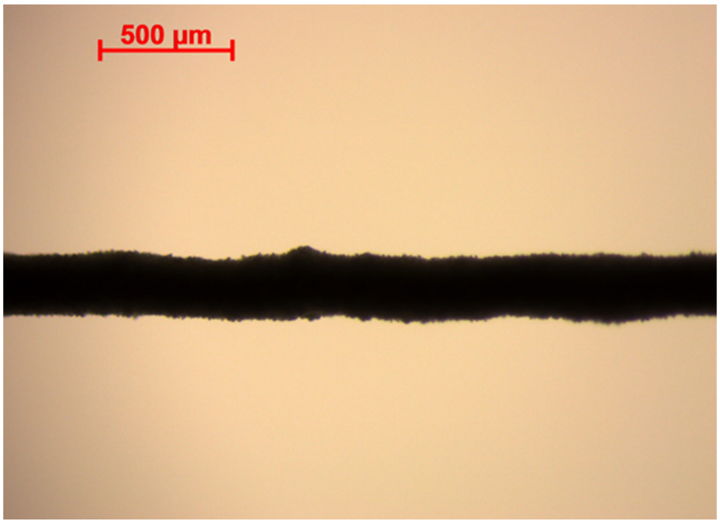
Figure. 8.10 Photograph demonstrating issues with coating (Specimen Si1): Yarn placement

8.3.3 Findings: Experimental Series II

Specimen code[9]	Deposition time *(mins)*	Average diameter *(μm)*	Standard deviation *(±μm)*	Difference[13] *(μm)*
Base yarn *(uncoated steel-97% & copper-3%)*	0	45.7	2.6	-
Si14; Si16; So4; So5; So9; Si18	5	144.6	2.9	98.9
Si15; Si11; Si19	10	254.3	71.4	109.7
Si17; Si20	15	245.4	13.0	0.1
Si12; Si21	25[14]	245.2	5.6	-0.2
So8	30	245.2	5.6	-0.2

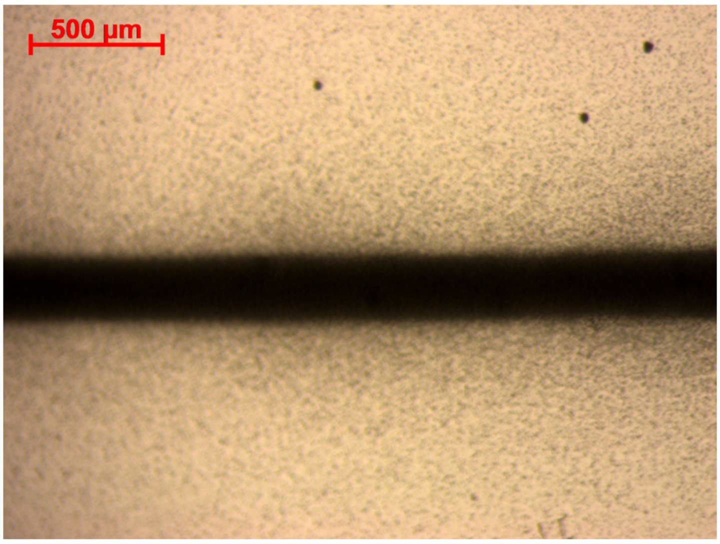


Si-13 ~5mins coating

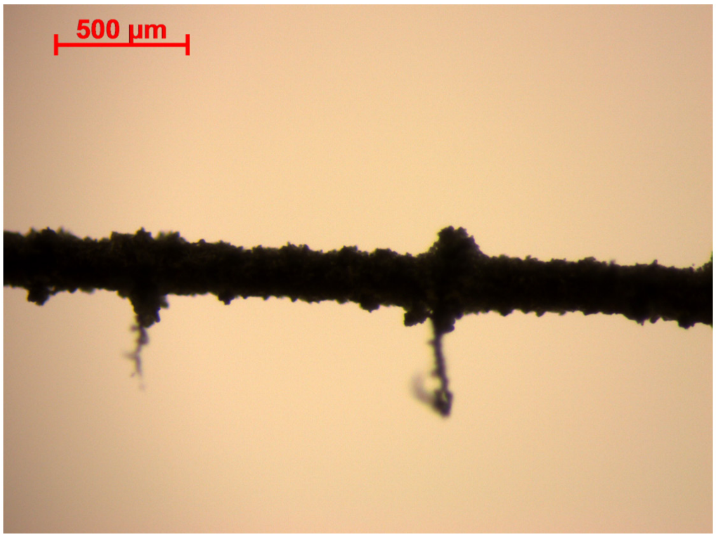


Si-15 ~15mins coating

Figure. 8.12 SEM of Specimens (left to right): Si13, Coating duration ~5 minutes; Si15, Coating duration ~15 minutes; Si 16, Coating duration ~25 minutes; Si14, Coating duration ~130 minutes.



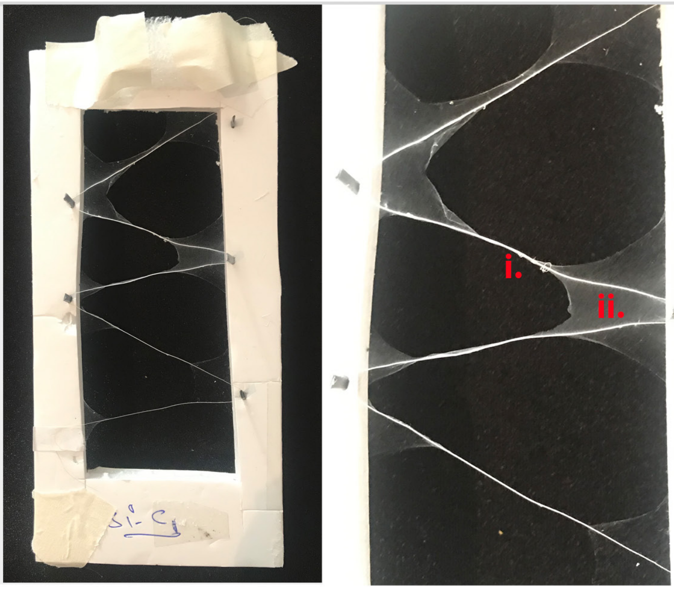
Si-16 ~25mins coating



Si-14 ~130mins coating

Figure 8.13 Photo compilation 1 of yarn specimens Si1 to So9. Demonstrating yarn quality (namely in terms of uniformity of coating) visible to the naked eye of a textile researcher (Author's archive)

Si1

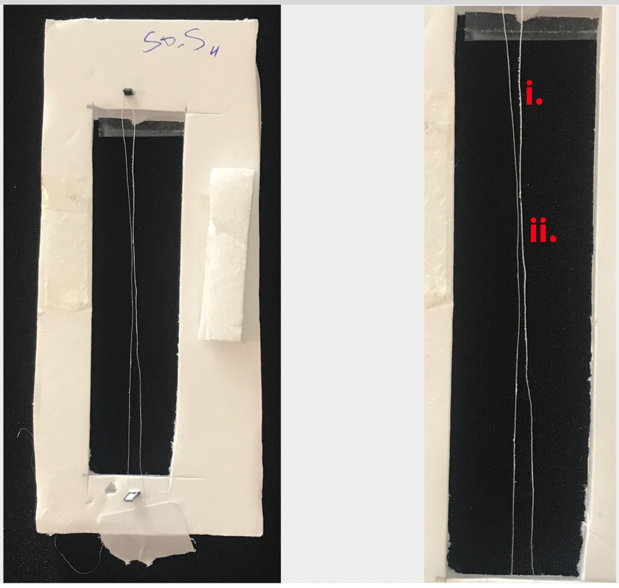


Specimen Si1
[**i. Poor yarn quality**; **ii. 'Web' formation due to yarn shaping in frame**]

Si2

[**i. Poor yarn quality**; **ii.** '

So4

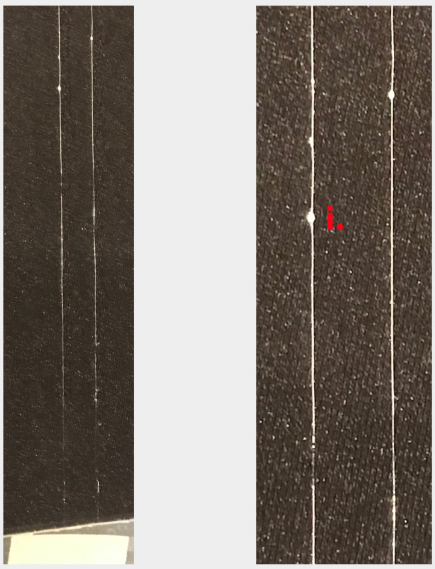


Specimen S04
[**i. Poor yarn quality**; **ii. Issues with yarn contact:** 'looped' yarn arrangement]

So5

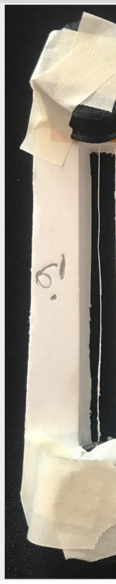
[**i. 'Break points':** fibers

Si7

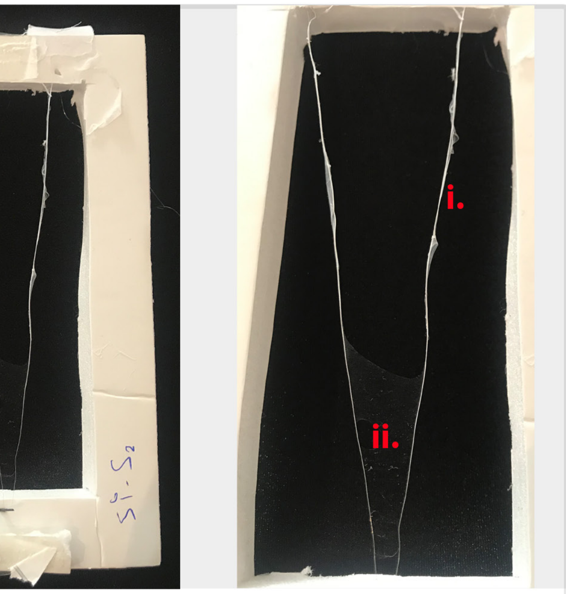


Specimen Si7
[**i. Poor yarn quality:** Minimal coverage and beading]

So8

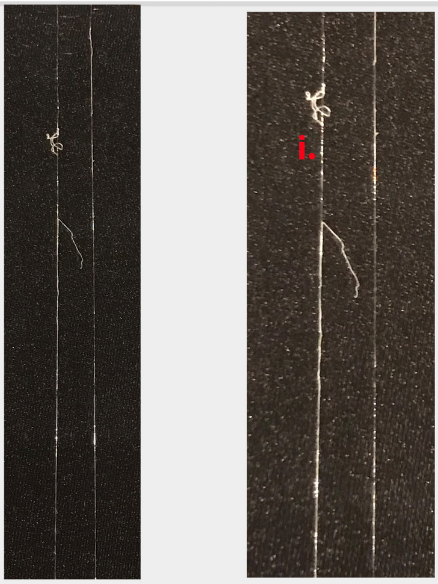


[**i. Poor yarn quality:** Unifor

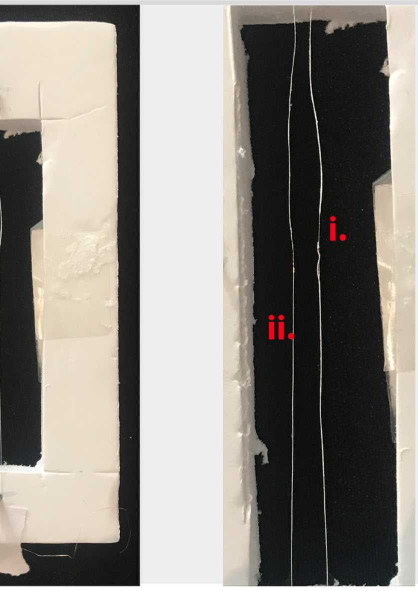


Specimen Si2
Web' formation due to yarn shaping in frame]

Si3

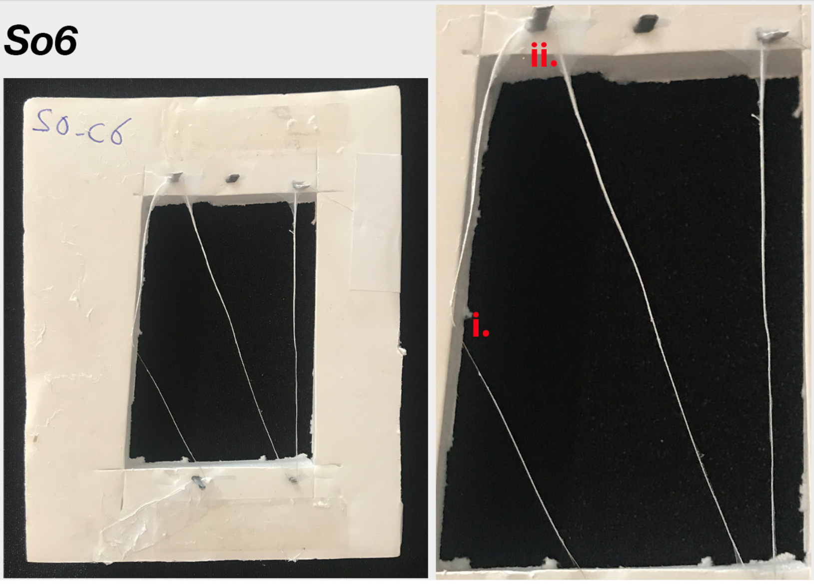


Specimen Si3
[i. **Poor yarn quality:** Minimal, irregular and damaged coverage]



Specimen So5
brushed off with contact; ii. **Minimal coverage**]

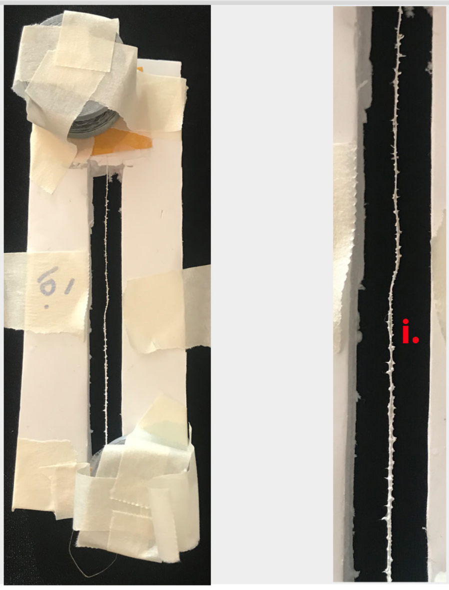
So6



Specimen So6
[i. **Poor yarn quality:** Contact with yarn; ii. **'Web' formation**]

Specimen So8
mity; ii. **Nanofiber 'build up':** Deposition ~30 mins]

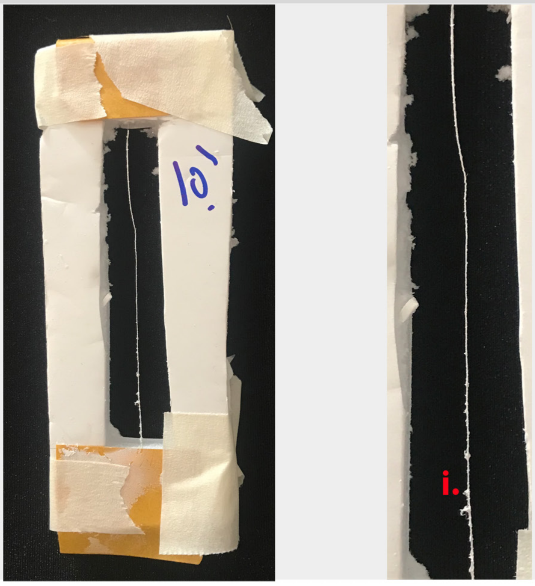
So9



Specimen S09
[i. **Poor yarn quality:** 'Spikes' in coating - Deposition time 5mins]

Figure 8.14 Photo compilation 2 of yarn specimens So9 (repeat) to Si13 (repeat). Demonstrating yarn quality (namely in terms of uniformity of coating) visible to the naked eye of a textile researcher (Author's archive)

So9
(repeat)

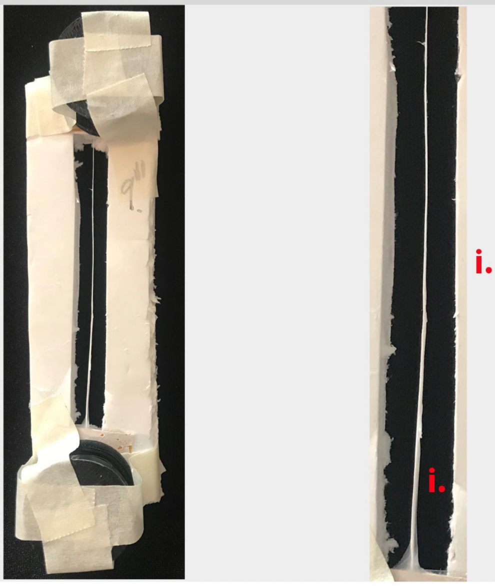


Specimen S09 (repeat)
[i. **Reduced, albeit still present, 'spiking' in coating:** Deposition time 5mins]

Si10

[i. **Nanofiber 'bui**

Si11
(repeat)

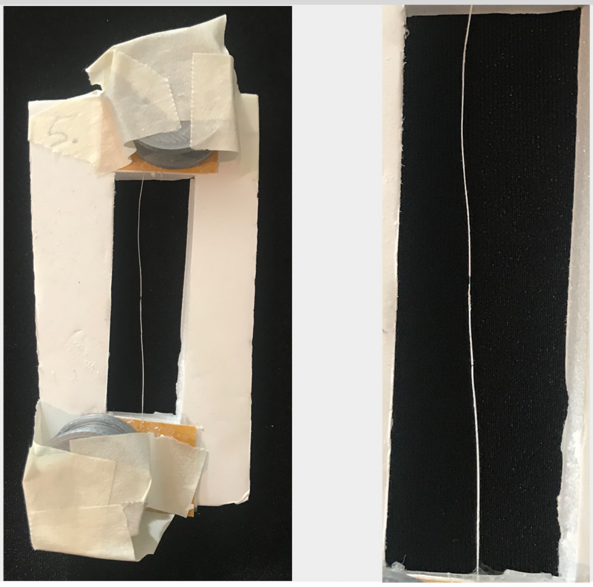


Specimen Si11 (repeat)
i. **'Build up':** Deposition time ~8 mins

Si11
(second repeat test)

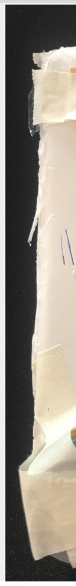
Specimer
[i. **Poor yarn**

Si12
(repeat)



Specimen Si12 (repeat)
[i. **Minimal damage:** 'Break points' - reasons unknown]

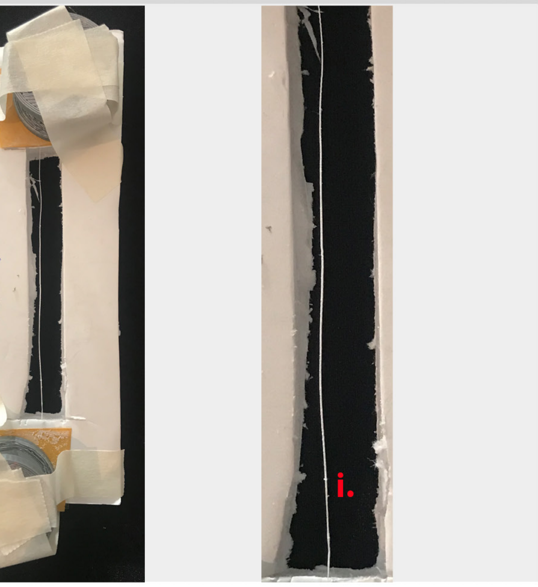
Si13



S
[i. **Improved co**

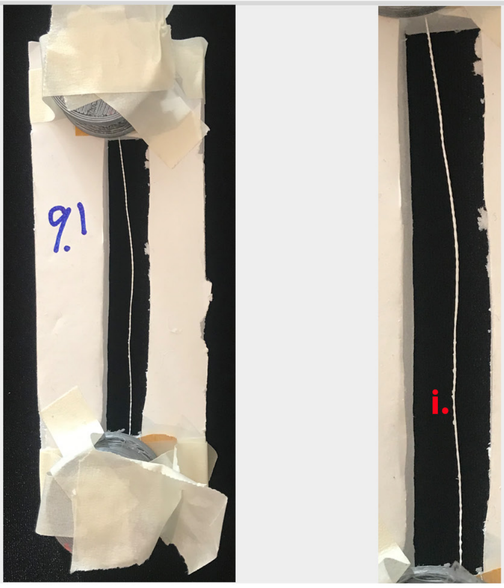
Specimen Si10
[...ld up':** Deposition duration ~20 mins]

...n Si11 (second repeat)
...**quality:** Coating uniformity]



...pecimen Si13
...**ating:** Deposition time 20mins]

Si11

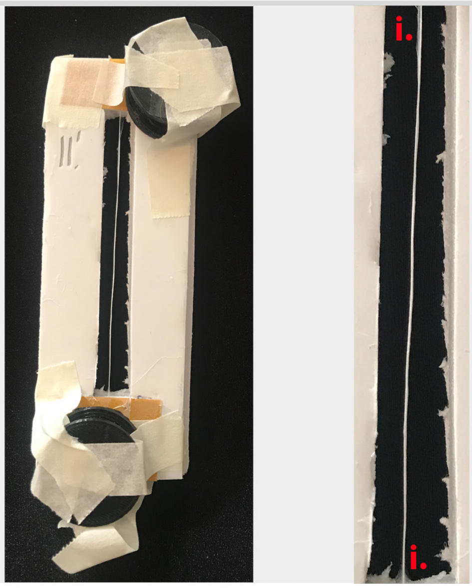


Specimen Si11
[**i. Poor yarn quality:** Lack of uniformity in coating]

Si12

Specimen Si12
[**i. Poor yarn quality:** 25 mins deposit time]

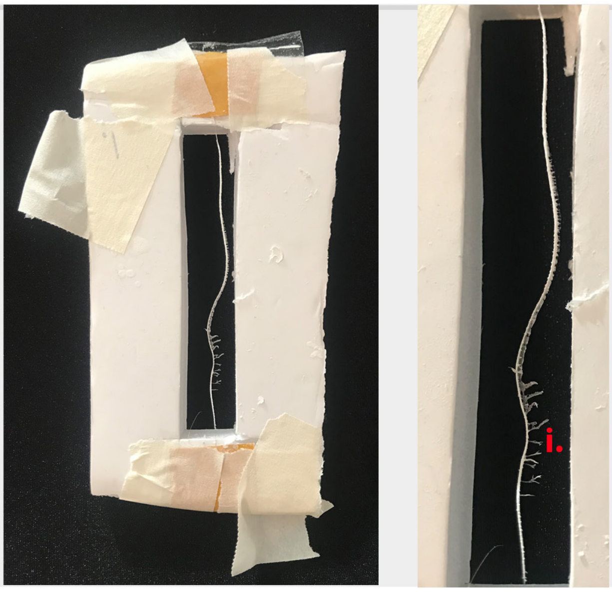
Si13
(repeat)



Specimen Si13 (repeat)
[**i. 'Build up':** At contact points with frame. Deposition time ~20 mins]

Figure 8.15 Photo compilation 3 of yarn specimens Si14 to Si21.
Demonstrating yarn quality (namely in terms of uniformity of coating) visible to the naked eye of a textile researcher (Author’s archive)

Si14

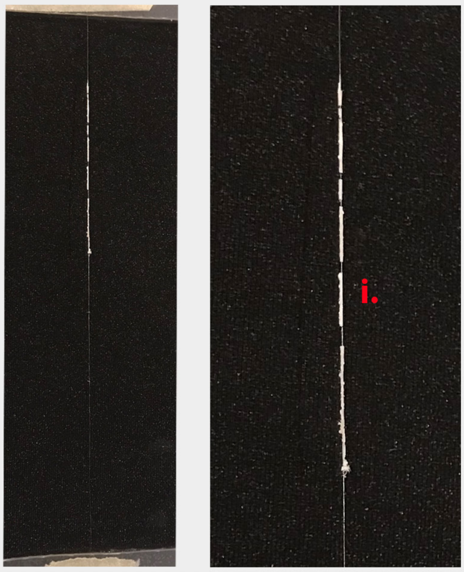


Specimen Si14
[i. Yarn quality still compromised after repeat in linear arrangement]

Si15

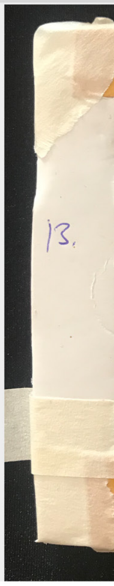
Specimen Si15 (repeat
[i. irregular surface

Si17



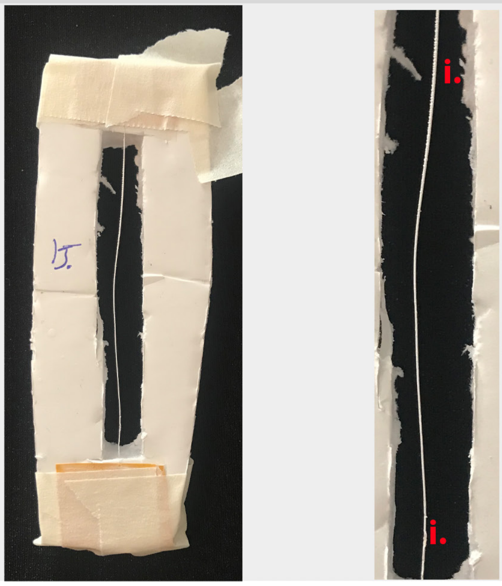
Specimen Si17 (post test-rig testing)
[i. Remaining nanofibers following testing on test rig]

Si18

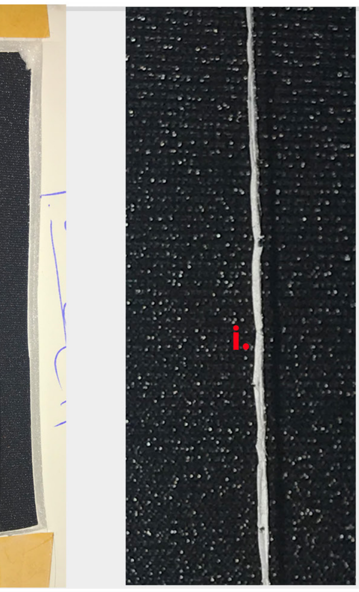


[i. Improved yarn quality: G

Si20

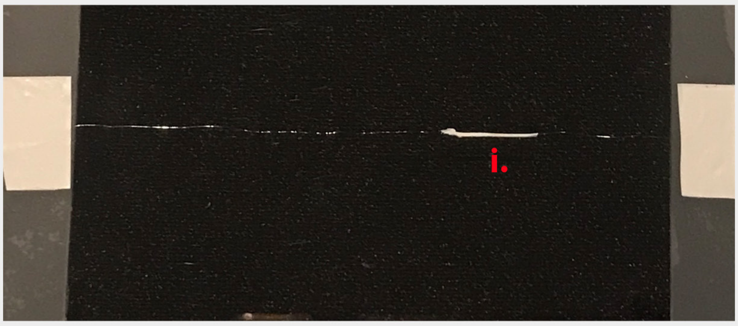


Specimen Si20
[i. Improved uniformity in coating: Deposition time 15mins]



t of Specimen Si2 in linear configuration)
coating remains but without webbing]

Si16



Specimen Si16 (post test-rig testing)
[i. Remaining nanofibers following testing on the test rig]

Specimen Si18
reater coating uniformity- Deposition time 5mins]

Si19

Specimen Si19
[i. 'Spiking' in coating: Deposition time 10mins]

]

Si21

Specimen Si21 [i. Yarn quality (surface uniformity) reduces and webbing increases with increased deposition time ~25mins]

8.4 Material characterisation and testing: A case study analysis of yarn Concept one

8.4.1 Test aims and methods

To test the effectiveness of the yarns, Differential Scanning Calorimetry (DSC) analysis was conducted on the specimens to determine the presence of the beta phase in the sample (Soin et al., 2014; Park et al., 2019). There are limitations to the data gathered, since DSC analysis only provides an indication of whether beta phase is present or not. It does not provide details on the percentage of beta phase fraction in the sample which likely varies according to the variables used in the experimental electrospinning process. Therefore, in partnership with the UK Atomic Energy Authority, X-ray Diffraction (XRD), Scanning Electron Microscopy (SEM) analysis and piezo response testing using an Instron tensile tester and oscilloscope were conducted to provide information about the percentage beta phase fraction, surface morphology and voltage generated from the yarn specimens.

Section 8.4.2 will firstly explore DSC analysis, before sections 8.4.4 to 8.4.6 will detail XRD, SEM and piezo response testing respectively.

8.4.2 Experimental conditions: DSC

Crystallisation properties and polymorphism of the neat and nanofiber yarns was studied by DSC analysis within the temperature range of 298 - 523K (25 - 250°C) at a heating rate of 10K/ min under N_2 atmosphere (100ml/min). The specimens were prepared by brushing off the PVDF coating from the core yarn and mounting them onto a crucible (Figure 8.16). Unprocessed pellets were also analysed and used as baseline measurement for comparison to the electrospun samples.

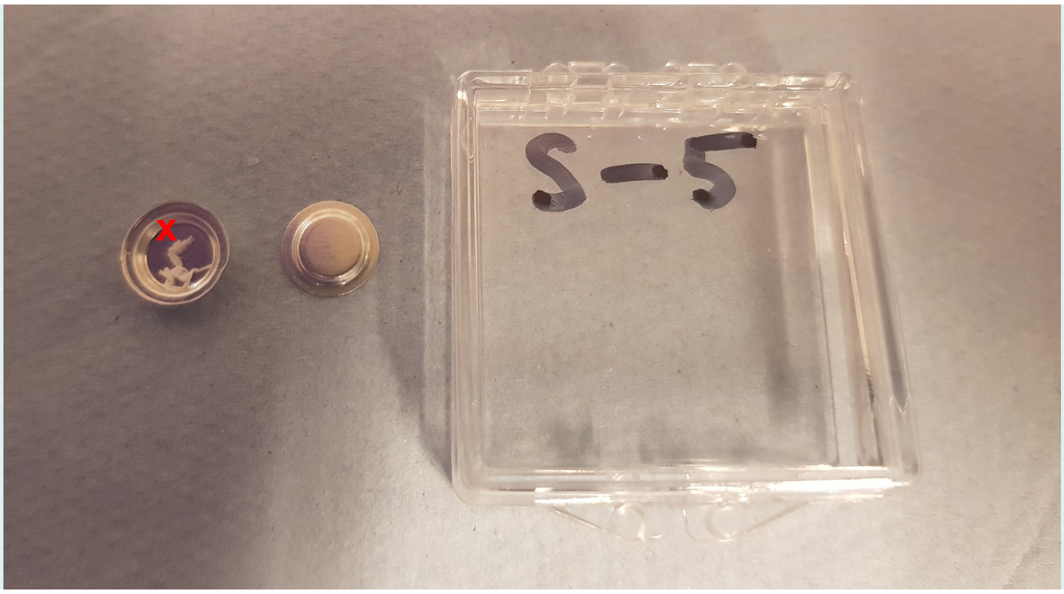


Figure. 8.16 Specimen Si12 mounted in the crucible (point x)

8.4.3 Findings: DSC analysis

According to the literature (Wan and Bowen, 2017), the following temperature peaks indicate the presence of the following phases:

1) A peak at ~172-175°C for Alpha
2) ~167-172°C for Beta
3) And ~175-180°C for Gamma

Table 8.17 shows the peak values for a random selection of Specimens; supplemented by Figure 8.18 displaying their graphical representations. All samples tested display the presence of beta phase. However, the limited mass of some samples (e.g. So5) resulted in low quality readings. It is difficult to suggest whether Specimens So5, So6 and So9 display alpha or beta phase. Further analysis (e.g. X-ray diffraction [XRD]) is required to examine the percentage fraction of the phases present within the Specimens.

Table 8.17 DSC analysis data

Specimen	**Key**	**Mass** *(mg)*	**Temperature peak** *(°C)*	**Corresponding phase** *(Alpha [α]. beta [β]. gamma [γ])*
Unprocessed pellet *(Solef-1008)*		37.73	~185	γ
So5		0.04	~170	α / β
So6		0.63	~172	α / β
So9		0.46	~170	α / β
Si11		2.52	~167	β
Si12		0.36	~167	β
Si13		1.33	~167	β
Si14		0.48	~167	β
Si19		0.92	~167	β

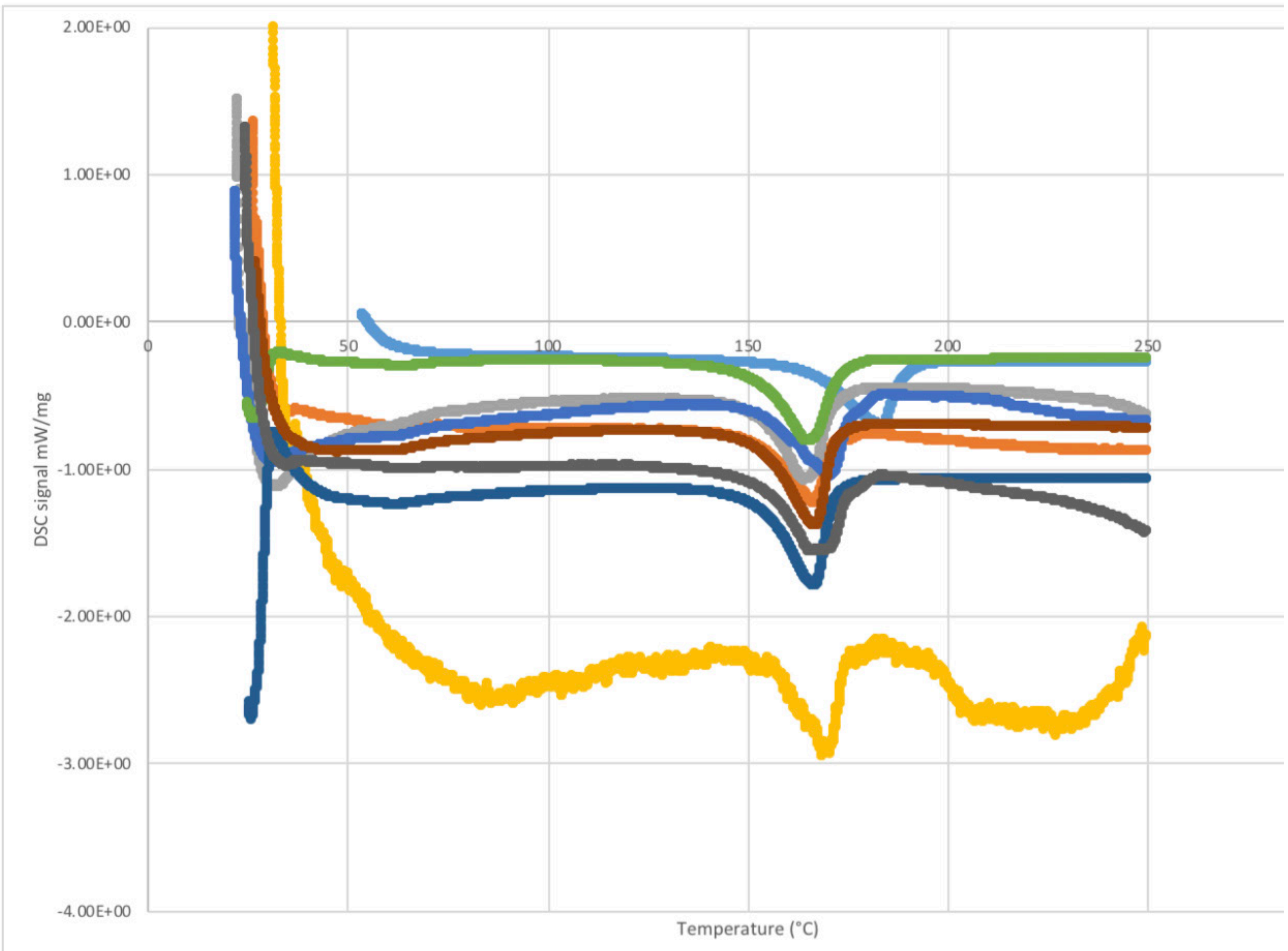


Figure 8.18 DSC analysis of Specimens Solef 1008 to Si19 (Table 8.40)

8.4.4 XRD analysis of specimens

8.4.4.1 Aims and issues

The aim of the XRD analysis is to measure the %wt of the crystalline phases (alpha, beta and gamma) within the PVDF coating on the yarn specimen.
One issue is that the X-ray penetration depth for PVDF is about 0.5 mm. Each specimen contains only 2 to 3 mg of PVDF per sample. Given the 1.78 g/cm^3 density of the PVDF, the penetration depth is therefore only 1 to 2 cubic millimetres. This means, no matter how the samples are arranged, the X-rays will penetrate through it and hit the sample plate or container used to hold the sample. In addition, this is a very small amount of sample made of light elements, which suggests that weak signals will be obtained making it difficult to determine %wt of crystalline phases.
Removing the PVDF coating from the core yarn will likely impact results too.

As a result of this, an improvised 'beam stopper' and an air scattering protector were installed in an experimental set up (Figure 8.19) to reduce the background noise from the air scattering as much as possible.

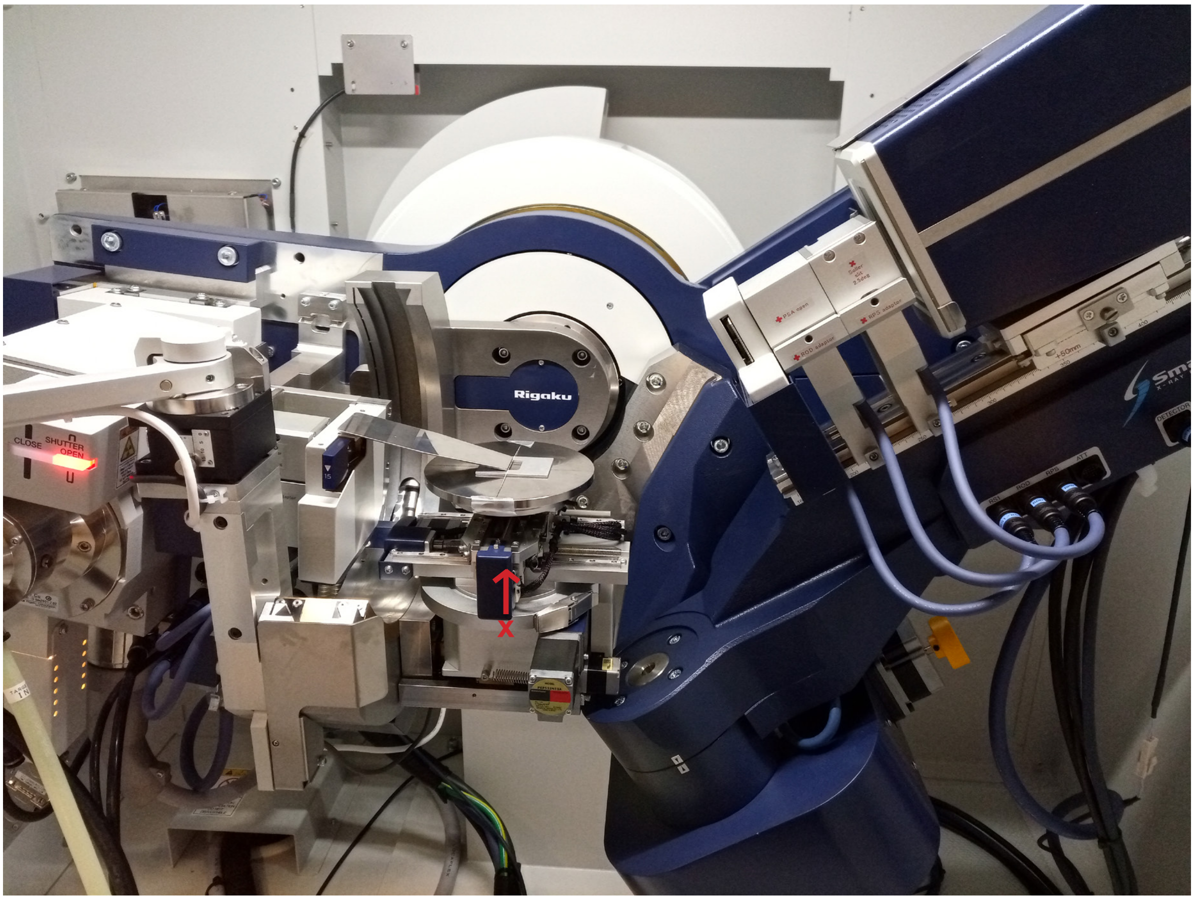


Figure. 8.19 XRD experimental set up for analysing yarn specimen [point x] (Author's archive)

8.4.4.2 Methods

The composition of PVDF coated Cu wires was determined by X-ray fluorescence analysis using Rigaku RIX 3000 spectrometer with some adaptions to the set-up. Adaptions had to be made due to the nature of analysing PVDF coating on the wire. It was considered that removing the PVDF from the core Cu wire may affect results. Therefore the set-up was adjusted to accomodate this as follows:
PVDF coated Cu wires were stretched horizontally for the XRD measurement. To reduce background from air scattering an air scattering protector plate for the incident beam and a beam stopper for the transmitted direct beam was installed. The source to sample and the sample to detector distance were both 300 mm and 2.5° Soller-slits were used both at the incident and the receiving sides to reduce the horizontal divergence of the beam. The incident beam was kept fixed with respect to the sample to prevent the sample accidentally moving out from the beam due to slight misalignments, and the detector was scanning in 2θ from 5° to 45°. Figure 8.19 shows the photo of the experimental setup.

The specifications of yarn specimens tested are displayed in Table 8.20 below. The majority of specimens (Si5, Si-15, So-6, Si-9) were used from prior electrospinning experiments, whereas others (Si-18-1, Si-18-2, Si-9-2) were created specifically for testing with UKAEA based on DSC results.

Table 8.20 Specifications of yarn specimens tested

Specimen Code	Base Yarn	PVDF concentration (wt%)	Electric Voltage (kV)	Flow rate (mL/h)	Deposition time (mins)	Ambient temperature °C	Hur (
Si-18-1	97% Steel 3% Copper	18	15	0.2	10	17	3
Si-5		15	11	1	23	23	4
Si-15					15		
Si-18-2		18	12.5	0.2	20	17	3
So-6		15	17	1	35	22.5	4
Si-9		15	11		8	23	3

8.4.4.3 Results

Theoretical peak positions, relative peak intensities assuming texture-free sample, and Reference Intensity Ratios (RIRs) of the PVDF phases were calculated from crystallographic information files obtained from the Cambridge Structural Database. The weight fractions of the PVDF phases were estimated based on the integrated intensities of the fitted peaks taking into account the RIR of the corresponding phase and the relative intensity of the peak with respect to the highest intensity peak of that phase. For β-PVDF the first 2 reflections, (200) and (110) were fitted as a single peak, because they are so close to each other, that they cannot be resolved as separate peaks. This single fitted peak was used to determine the weight fraction of the β-PVDF phase.

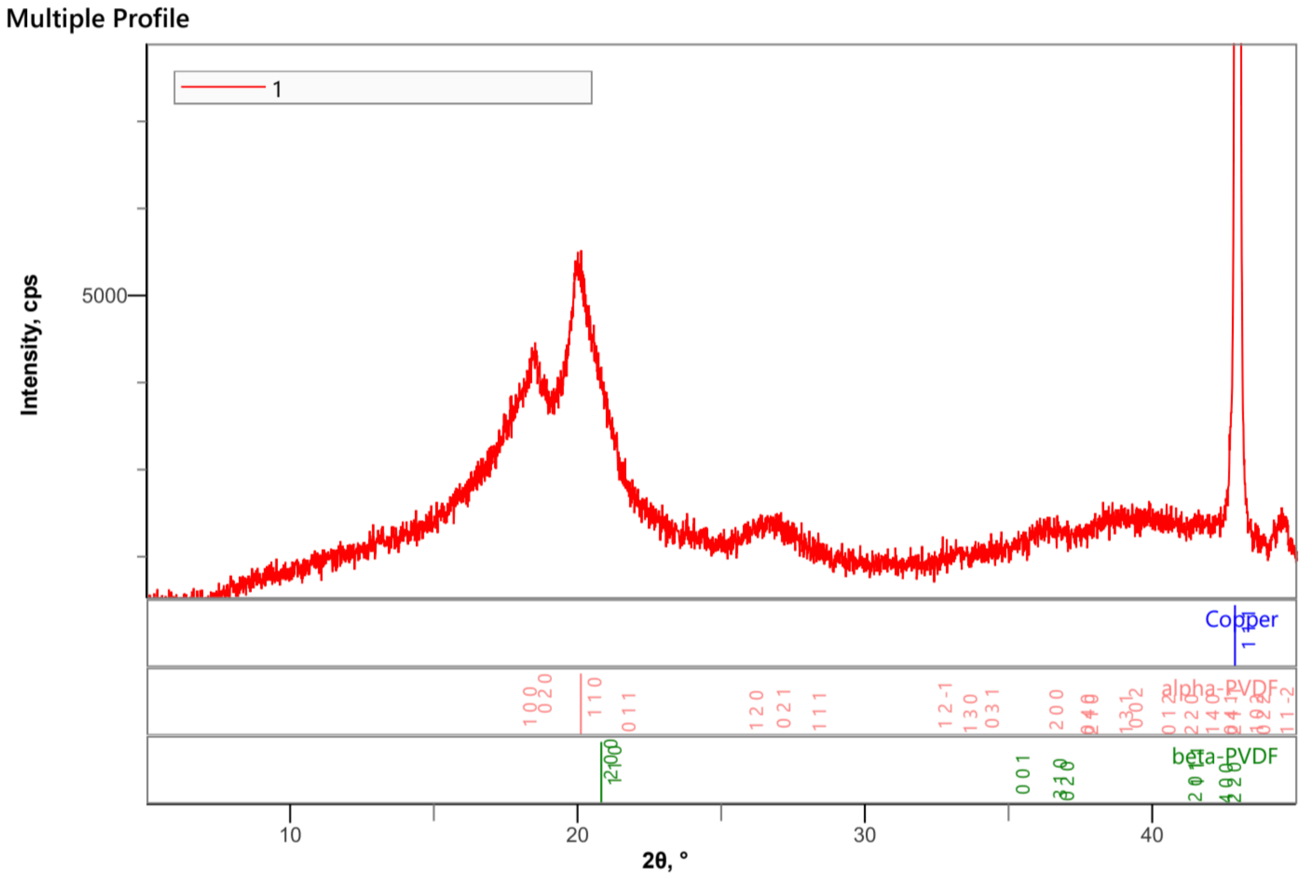
The weight fractions given in the CIF files have to be corrected for two reasons: i) they include the copper wire, but this is not really meaningful as the intensity of the copper reflection with respect to the PVDF strongly depends on geometrical factors and it is not the subject of the present analysis either, and ii) it was not possible to assign both the (110) and (200) reflections of the β phase to the same fitted peak in the Rigaku software. Therefore, only the (110) β-PVDF was assigned to the 4th peak, which is the strongest reflection of the β-PVDF phase and the point of focus in the experiment.

By multiplying the weight fraction of the β-PVDF phase by 100/138.33 and renormalizing the sum of α-PVDF and β-PVDF fractions to 100 wt% one gets the weight fractions given below in Table 8.21 and Figures 8.22 to 8.23 displaying raw XRD data from specimens Si-18-1 and Si-18-2 respectively. The results will be discussed collectively with the peizo response results in Section 8.4.6.

Table 8.21 Measured weight fractions of PVDF phases

Specimen Code	α-PVDF wt%	β-PVDF wt%
Si-18-1	89.2±3.0	10.8±3.0
Si-5	88.9±1.7	11.1±1.7
Si-15	87.5±1.4	12.5±1.4
Si-18-2	40.9±1.0	59.1±1.0
So-6	52.8±1.9	47.2±1.9
Si-9	75.3±2.2	24.7±2.2

a)



b)

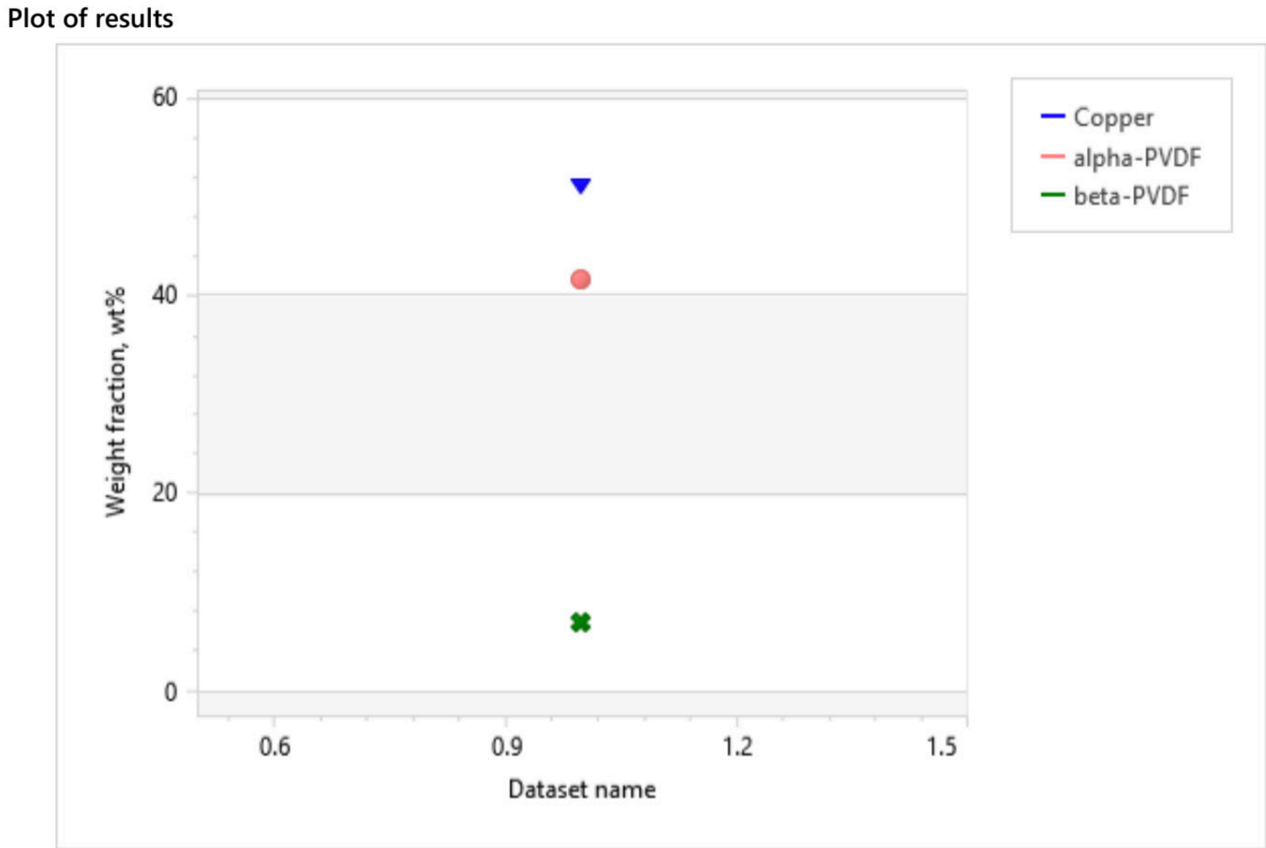
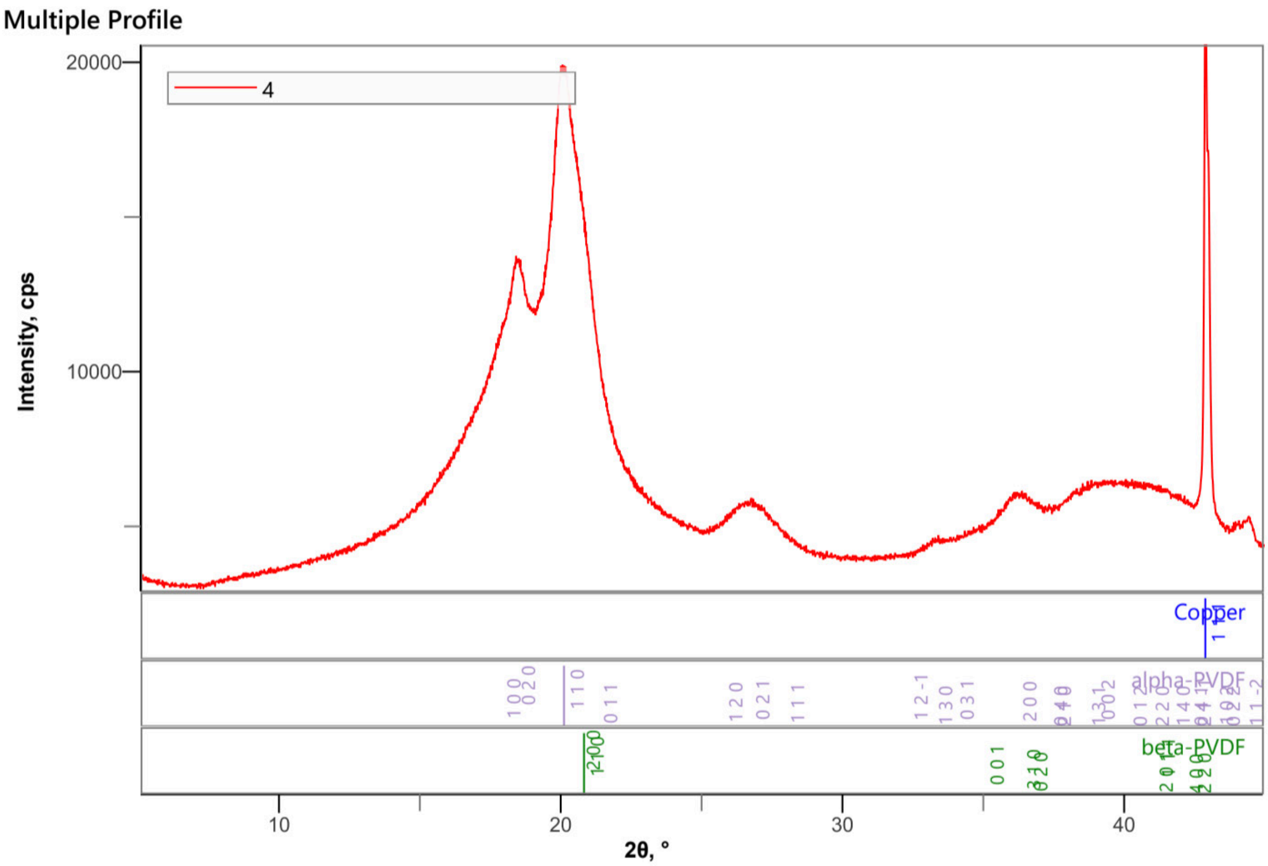


Figure. 8.22 Specimen Si-18-1: a) Peak process graph; b) Plot of results detailing wt% of the core yarn, alpha and beta fractions of PVDF

a)



b)

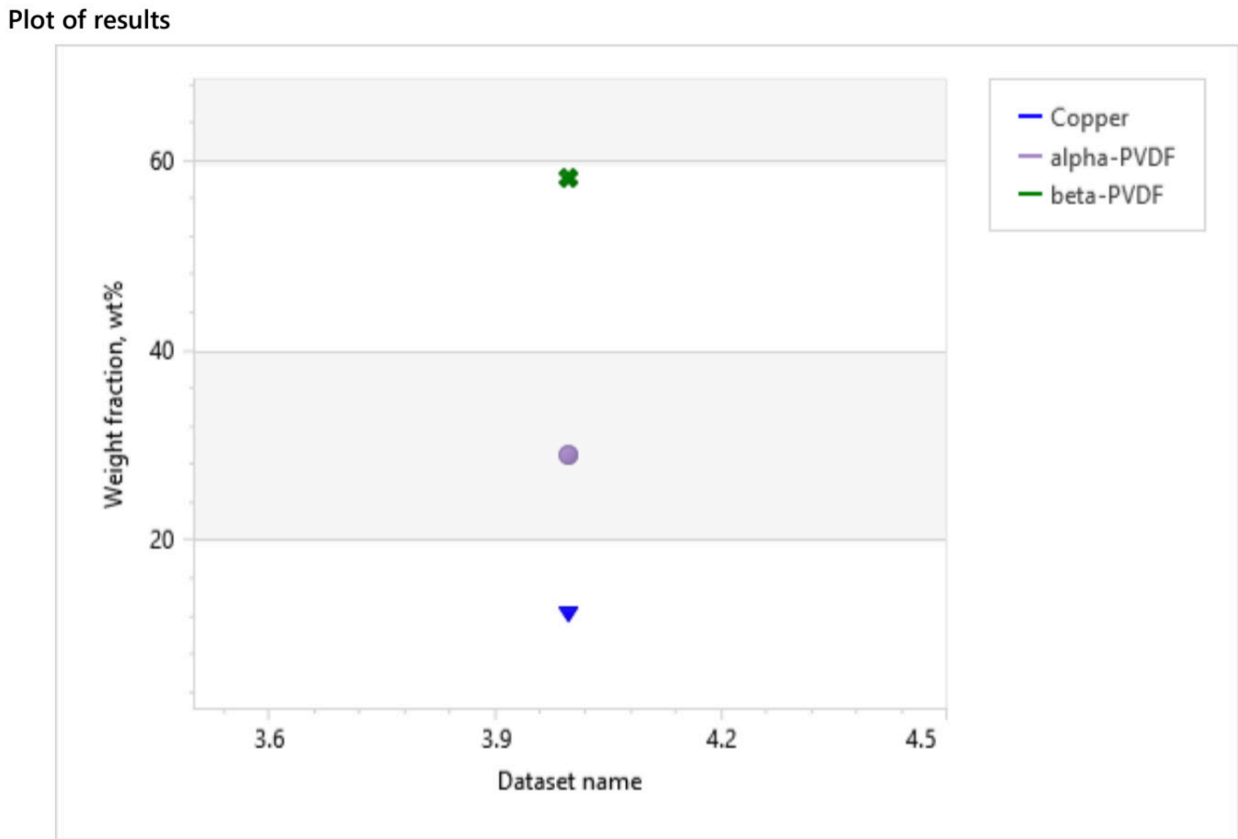


Figure. 8.23 Specimen Si-18-2: a) Peak process graph; b) Plot of results detailing wt% of the core yarn, alpha and beta fractions of PVDF

8.4.5 Piezo response testing

8.4.5.1 Aims

The aim of piezo response testing is to determine how much voltage is generated from the yarn specimens at a given strain rate. This can then be used to indicate what percentage of the total power requirements of a device can be fulfilled via the yarn specimens and therefore how appropriate it may be to use.

8.4.5.2 Methods

Yarn specimens detailed in Table 8.21 with a total coated length of between 84 - 102mm were tested using an Instron tensile tester, TRAPEZIUMX and Picolog programmes, data logger and oscilloscope. The aim is to measure the potential between the core yarn and the coating (Figure 8.24) using Shimadzu AGS-X capstan wire grips. Testing was conducted at a speed between 0.1mm/min to 2mm/min.

In order to connect the oscilloscope to the PVDF coating, the ends of the data logger wire was twisted around the coating (Point x on Figure 8.25). To maintain adequate grip to the yarn, the ends of the yarn are sandwiched between acrylic sheets, cut to appropriate thickness, before being placed in the grippers. The neutral wire from the control box on the data logger is connected to the core yarn and the other wire is connected to the piezo coating.
To avoid the weight of the wire affecting results it was deweighted by suspension on the equipment (Point y on Figure 8.25) whilst the value of the load cell was monitored to detect any changes impacting strain applied to the specimen.

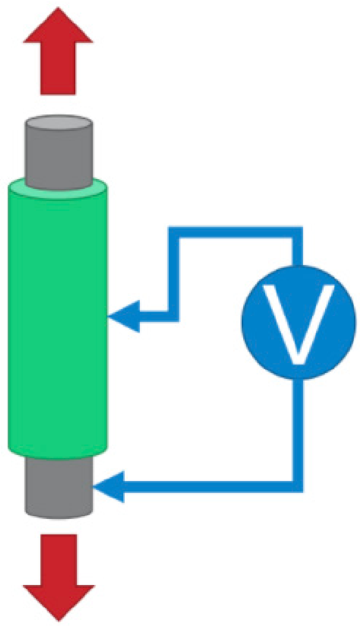


Figure. 8.24 Illustration indicating the positioning of wires connected from the oscilloscope to the yarn specimen

Strains of 25% intervals were tested, within the elastic limit; i.e. 25 cycles at 25% strain, 25 cycles at 50% strain, 25 cycles at 75% strain and finally 25 cycles within 90% strain. Strains were fully released between each cycle. However, due to budget limitations, cycles varied up to 25 at each strain (see Table 8.27).

Peak strain is calculated using just core conductive yarn and a duplicate PVDF nanofiber yarn provided in order to determine the maximum % strain explored in each cycle.
A sample core yarn of 40mm in length has 300microns of elastic yield - strain is ~20%
Excess noise seen in the data (see figure x). This is due to the equipment having a large range (up to 10,000N) and operating at a range below 1N, which was expected. Therefore the software will not use the Force as the independent variable to determine the value tested, rather we will control the experiment via the displacement value. Therefore, Force = dependent variable and Displacement = independent variable. Peak strain is recorded at ~0.64N.

Figure. 8.25 Overview of set-up of yarn specimen in Instron Tensile Tester [Point x: Indicating connection between PVDF coating and data logger wire; Point y: Indicating de-weighting technique] (Author’s Archive)

8.4.5.3 Results

Results were captured from the data logger onto the PicoLog programme (Figure 8.26) and are summarised in Table 8.27. Voltage was observed in just two specimens (Si-15 and So-6) in Figures 8.28 and 8.29 respectively. As with the XRD data, results from piezo testing will be discussed in Section 8.4.6.

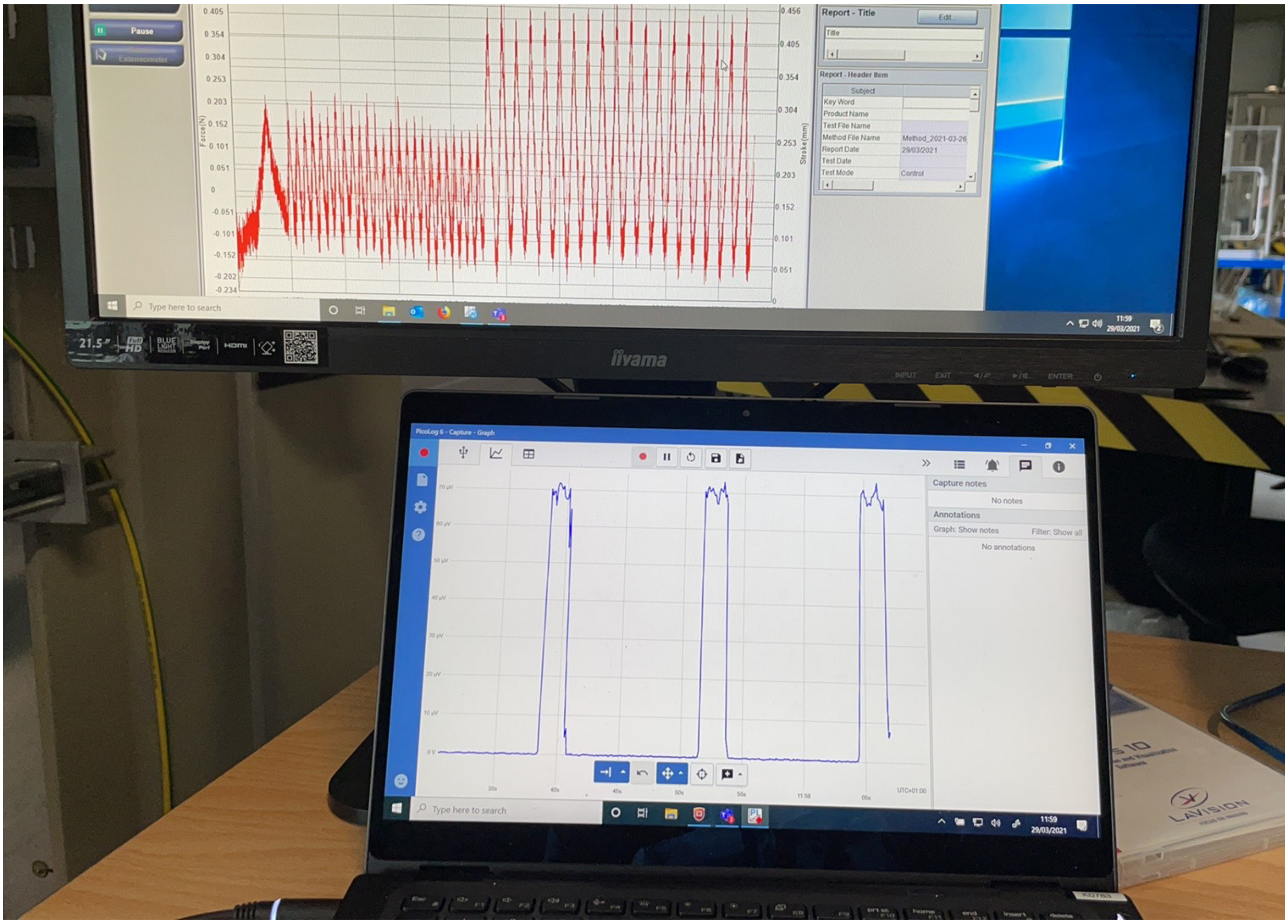


Figure. 8.26 Snapshot of data collection in progress [Note, this figure is included for the purpose of providing context. Results displayed are not intended to be legible] (Author’s archive)

Table 8.27 A summary of parameters and observations in tested specimens

Test ID	Specimen Code	Number cycles per strain rate				Gauge Length (mm)	Test Speed (mm/min)	Comments
		25%	50%	75%	90%			
1	Si-18-1	25	25	29	0	84	0.4	No voltage observed
2	Si-18-1	0	0	6	25	84	2	Test speed increased to complete testing
3	Si-5	25	25	25	25	92	2	No voltage observed
4	So-6	25	25	25	25	102	2	Voltage spikes (200μV to 1mV) seen at bottom of loading cycle
5	Si-15	13	0	0	0	86	2	Test stopped prematurely for unknown reason.
6	Si-15	25	20	0	0	86	2	Force not zeroed correctly (zero error). True force is ~0.15N greater than indicated force. Test stopped prematurely for unknown reason.
7	Si-15	25	6.5	0	0	86	2	Updated method to remove 'break detect' - assumed to cause stopping issue.
8	Si-15	0	0	25	0	86	0.4	Voltage spikes (70-100μV) clearly seen. Test stopped after 75% strain cycles to speed up test. No voltage decay seen after test stopped.
9	Si-15	0	0	0	25	86	1	Voltage spikes visible (70-100μV)
10	Si-18-2	25	25	25	0	95	1	No voltage spikes seen
11	Si-18-2	0	0	0	25	95	1	No voltage spikes seen. Unexplained decrease in force observed during test (0 N --> -0.31N) - potentially a result of sun hitting test machine and warming up loadcell.
12	Si-9	25	25	25	25	98	2	No voltage spikes seen

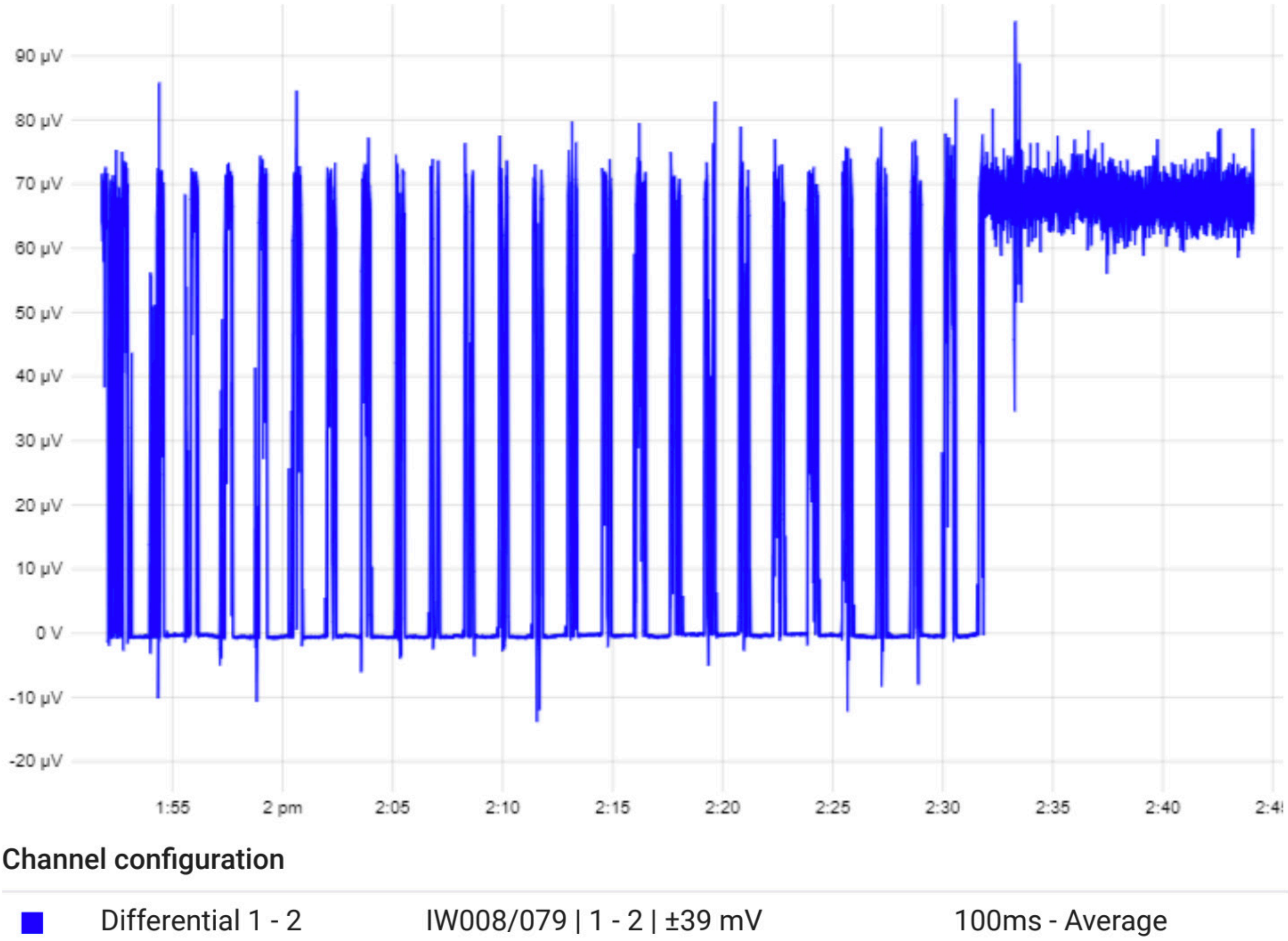


Figure. 8.28 Output voltage produced by specimen Si-15

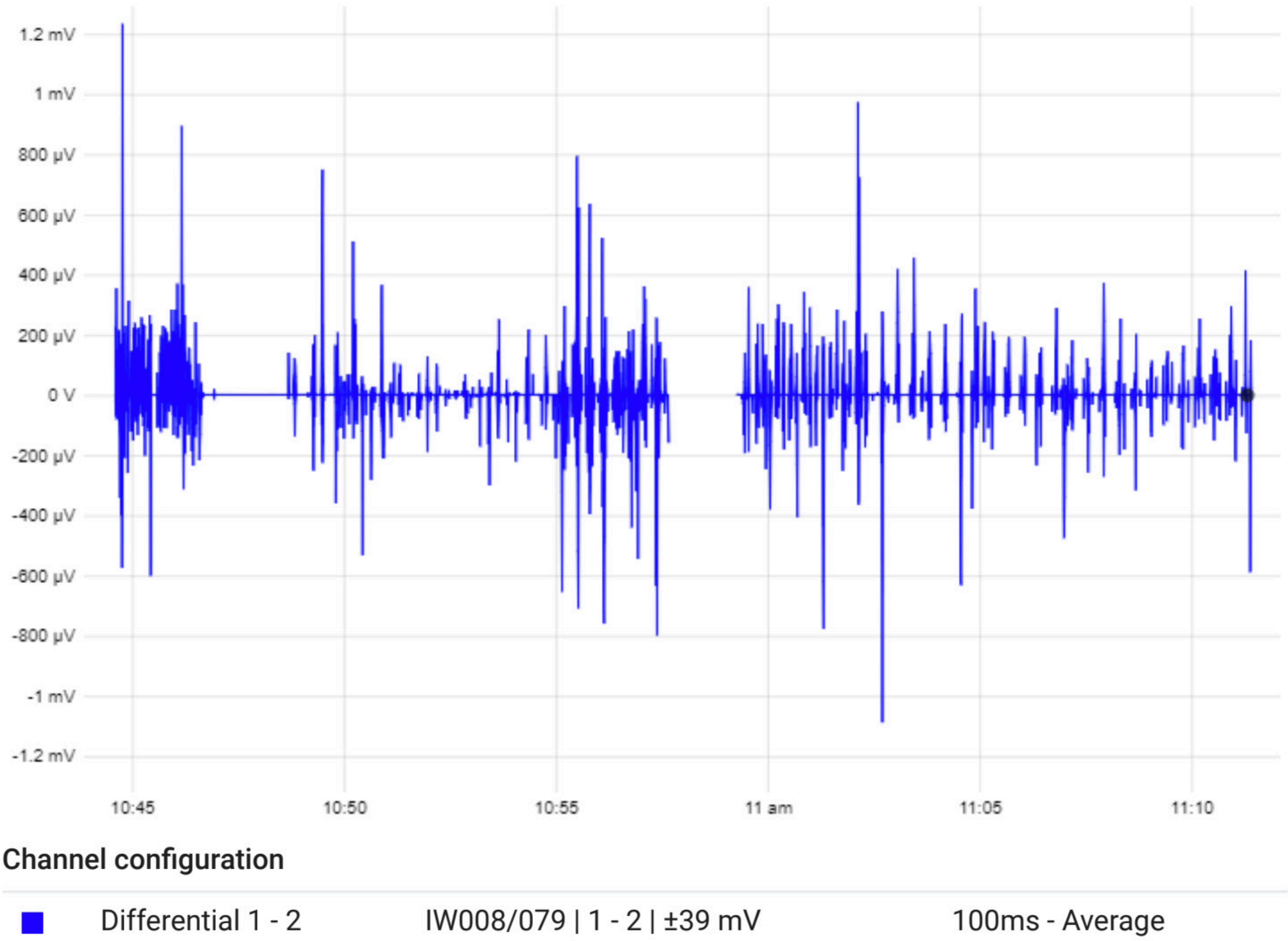


Figure. 8.29 Output voltage produced by specimen So-6

8.4.6 Discussion

In this case study, samples exhibiting higher wt% of beta phase fraction did not entirely correspond to observed output voltage detected in piezo response tests. Indeed, specimens Si-18-2 and So-6 demonstrated the highest beta phase fraction yet specimens Si-15 and So-6 were the only specimens demonstrating output voltage (70-100µV and 200µV and 1mV respectively). So-6 was consistent in demonstrating a higher beta phase fraction yet Si-15 recorded a 12.5±1.4 fraction. It is unknown why sample Si-18-2 did not exhibit a detectable piezo response, although this could be due to either issues with connectivity between the wire and PVDF coating, or noted issues with equipment in Table 8.27. Further repeat tests are required to explore this.

When exploring SEM analysis for further insight, spheres of PVDF were detected where nanofibers had not been successfully coated (Point x on Figure 8.30). Further, the delicate nature of the nanofiber coating could be seen with an outer shealth visibliy becoming detached from an inner core layer (Point y on Figure 8.31). The extent to which the outer shealth and therefore added thickness of coating is contributing to the piezo response is undetermined. However, deterioration in the coating likely impacts results. The application of an encapsulation layer may be deemed important prior to further tests. However, observations to interfacial bonding and material heterogeneity between the core yarn and nanofiber coating should be considered.

Further, the connection between the coating and the data logger wire can be improved. A gold (Ag) foil could be used to improve contact between the wire and coating whilst reducing the possibility of short-circuiting due to the nature of the foil being unable to penetrate through small gaps in the nanofibers, which gold sputtering techniques may do.

8.5 Chapter Summary

Energy harvesting methods have become popular areas for exploration within e-textiles. Yet, the limited capacity to generate enough power, as seen in the results captured in Section 8.4.5 within this case study but also in other studies can limit application to e-textile applications.

Although the voltage produced is limited, it is important to acknowledge:
Firstly, optimisation of samples may be achieved through a variety of methods. According to literature (Wan and Bowen, 2017), PVDF copolymerization can lead to a higher piezoelectric coefficient. After initial trials it may be necessary to use copolymers if the results are insufficient (Figure 8.2);
Secondly, the value of energy harvesting beyond functional performance, specifically, the value of re-thinking the roles of the wearer, textile components and therapeutic intervention. Indeed, it is worth considering the opportunities for how energy harvesting methods can influence behaviours of the wearer, behaviours that could benefit the therapeutic intervention's aims.

In this case study, promoting a mobile self is highly recommended even when rehabilitation is not offered (Section 1.2.2). Yet, it is also important to consider the challenges and issues that may be faced too. For example, how accessible is this for those more severely impaired where little to no movement is present, the use of energy harvesting methods that utilise body movement for powering the device could render the treatment inaccessible for some. That is even to say when energy harvesting materials are placed on areas of the body that are less affected and therefore exhibit movement. For those with moderate impairments who may be more mobile, the use of energy harvesting methods may be useful, yet it does not mean that individuals will make use of this function. If the e-textile components are powered via hybrid methods by both energy harvesting and battery packs, a reliance may be placed on battery power and energy harvesting left unused. That is, if energy harvesting is focused on producing energy from human movements. Alternative sources of producing energy may also be used that, although do not necessarily contribute to increasing a mobile self, may make steps towards more sustainable energy methods. Energy may be harvested from the force produced by the bead in delivering the tap stimulus. Further, from thermal energy produced by the electronic components and/or the human body.

The cost of integrating a hybrid system should also be considered, since the cost of the garment can limit access to some communities. Where this is not in the scope of this thesis to consider costs, this is an important element that needs to be acknowledged as something that can be a challenge for developing garment-based therapeutic devices.

Where Chapter eight has focused on technical investigations into the performance and opportunities of using energy harvesting materials, the value of how such materials can influence body behaviours and encourage greater mobility is considered interesting to pursue.
Chapter nine will investigate the integration of PVDF yarns, albeit melt extruded at this point until electrospun fibers are optimised, and further evaluate the bead, using an existing component (the voice coil) to do so.

CHAPTER 9.0

Exploring garment specifications: An insight into early garment development

9.1 Chapter 9.0 Overview

This chapter investigates the type of garment that is most suitable for the application of the 'bead' intervention in everyday use. Considerations for garment specification including seasonal requirements, shape, form and garment type are key if the 'wearable' is to be worn. Indeed, where the wearable is a therapeutic intervention, this can be particularly challenging. Trust is an important element when using a medical device, perhaps more so when that 'device' is a garment. How can the wearer be sure that the intervention is being delivered at the appropriate level? How can the wearer control the 'device'?

[The following text that appeared in the thesis was redacted due to its commercially sensitive nature.
Should the reader be interested in receiving the information please contact the author at: laura.salisbury@rca.ac.uk].

Within this Chapter key categories such as garment style, fit, positioning and visibility of 'components' are explored. Body scanning tools were used to visualise the body (Figure 9.1), with the resulting image becoming useful in; firstly, visually displaying the deficits described in the literature; and secondly, to be used when planning the positioning of the site of stimulation within garment developments. This was achieved by translating the body scans into a bespoke mannequin, e.g. Figure 9.2, enabling access to the body in times where this was restricted. Although the mannequin represents a static figure, not accounting for mobility, it enabled considerations for the posture, positioning and shaping difference of the affected and unaffected upper limbs to be analysed during garment development. The mannequin is based on a female participant[1] who has long-term upper limb deficits, dropped shoulder and contracture, representing a 'model candidate'.

[1] Future work includes body scanning of more individuals, to inform size variations and construct size charts.

Research insights have been compiled from throughout the thesis and additional participatory design sessions were run with the same participant groups (as Chapter seven) to establish and refine the garment specification, integrating the 'bead' (Figure 9.2). Section 9.3 details technical investigations interpreting the findings before summarising the working concepts developed, forming the basis of future research. The methodology for data gathering and analysis was kept consistent with protocols outlined in Chapter seven. Textile samples from Chapter seven and subsequent toiles developed during participatory design methods in this Chapter were used as design provocations. Participant responses informed developments of the garment specification. This is summarised in the following Section (9.2).

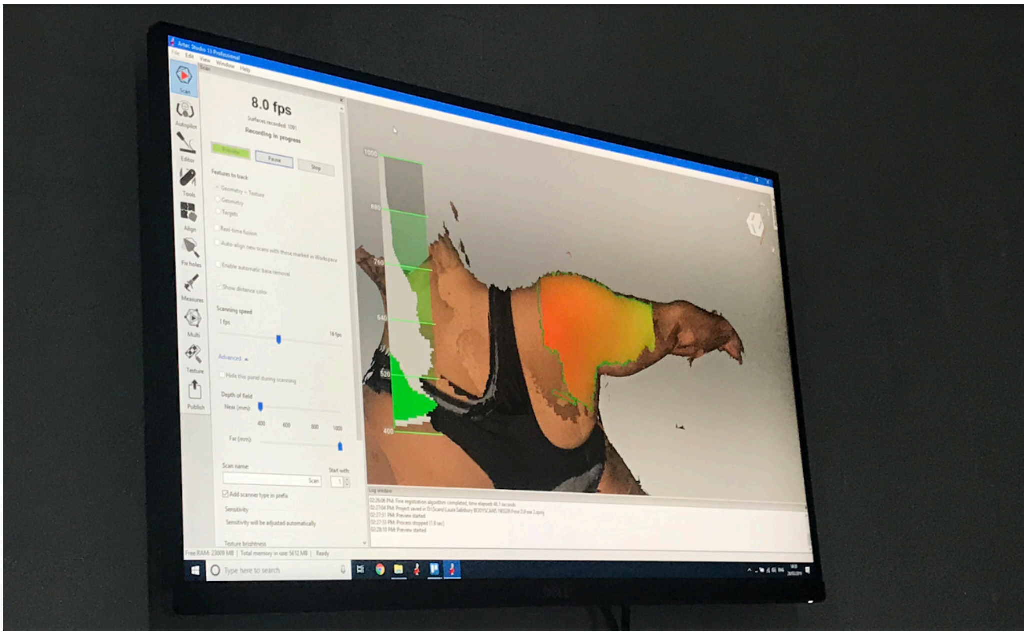


Figure. 9.1 From fMRI to Body Scanning: The body as a research tool (Author's archive)

9.2 Considering body image, garment type and 'component' visibility via participatory methods: Garment specification summary and discussion

Table 9.2 collates key findings from the participatory groups conducted throughout the final stages of the research. The findings demonstrate a consideration for integrating the stimuli within the garment. Modifications of the working specification includes considerations for behaviour during wear, dressing and aftercare. Accommodations are made for individual requirements. Where garment type varies according to personal style and bodily requirements (e.g. temperature), thoughts centre around common requirements to justify a final, representational prototype.

Table 9.2 Final garment specification: A summary

	Key findings
Garment type	1) The level of diversity in personal style, cultural, behavioural and context-dependent needs/ desires places a complexity on considering the most appropriate garment type(s) to deliver the stimulation. 2) Basic essential garments may be chosen for their wide acceptance in everyday contexts (PQ, 2020). 3) T-shirts, basic long-sleeved jersey tops, "comfy jumpers" (KL, 2019), base layers and undergarments became a focus of discussions amongst participants. 4) Figure 9.3 (created from Sample 45), Figure 9.4, 9.5, 9.6 and 9.13 in response to participant discussions. 5) Sleeve length may be varied according to seasonal requirements and personal style 6) Longer sleeves may be prefered in instances to avoid cold, stiff limb which can lead to pain and non-use 7) When integrating energy harvesting yarn, the pattern may vary depending on the placement and level of PVDF yarn content within the garment 8) Observations were conducted to consider the placement of the yarn in line with the range of body movements made by participants (Figures 9.7 and 9.8). Areas such as the elbow have been regularly identified and used in the literature as an area which harvests energy effectively (Ponnamma et al., (2019b). However, other areas such as the underarm area and shoulder/ cross-body area are also observed to provide substantial input. These areas, however, receive more 'wear' than others so the durability of the yarn and textile structures should take this into account 9) 'Pattern 1' (Figures 9.9 to 9.12) considered the placement of the energy harvesting yarn at areas which will yield significant energy. The panel shaping takes advantage of the elbow movements (although coverage could be better) as well as across the back and shoulders to account for residual movement from the upper limb that includes the shoulders and top of the back. The shaping around the forearm also accounts for the positioning of the 'bead' (point V., Figure 9.10) as well as reducing the amount of yarn used to the areas of most impact. 10) However, this did not account for the underarm area nor take advantage of gathering when seated and ranges of changes in tensile and compressive stresses in the garment around the waist. A further toile was created in response to this need (Figure 9.13), presenting panelled sections that include the underarm areas and a graphical representation of this as a long sleeved jumper is displayed in Figure 9.14. 11) Figure 9.8 demonstrates pattern considerations for use within clinic contexts. Garments for use within the early stages of recovery will likely require additional considerations for other procedures that occur, changing the garment specification. This presents as a thought although changes the vision of the garment from the everyday to 'adaptive', even "medicalised" (FF, 2019).

Garment fit	1) The fit of the garment impacts the function of the component in meeting the needs of the stimulation protocol; i.e. in supporting indentation, consistent and accurate positioning on the body including the efficiency of the energy harvesting yarns. 2) The majority of participants preferred a loose fitting garment (91%), with only 9% preferring a more fitted style. 42% stated that a looser fit was easier to dress into: *“not too tight because you need to be able to push your hand through easily without needing to use too much force [with the affected arm]”* (TT, 2019). 3) The degree of stretch can be dispersed to varying amounts throughout the sleeve; so that a looser fit may open up the sleeve head and cuff to enable the arm to be easily dressed into the sleeve, obtaining a tighter fit at the site of stimulation.
Textile structure	1) A tubular spacer structure (left) improves output performance of the energy harvesting yarn in Hypothesis 1.0 2) For Hypothesis 2.0 the textile structure is not limited
Yarn combination	1) Integrating lycra to control the fit of the garment, level of indentation of the bead to the limb and positioning of the bead 2) For Hypothesis 1.0, lycra can increase the overall stretch ratio of the textile supporting the output performance of the energy harvesting yarn
Use of the garment	1) The intuitive, universal nature of knowing how to wear a garment is of benefit to using the stimulation ‘device’. This also affects set-up time/ application to the body, which can reduce the time the physiotherapist has with the individual if this is too long or difficult, reverting back to methods they know best (Stockley, 2019). 2) There exists a need for the wearer (or clinician) to control the device, to switch it off, therefore removing the need to take the garment off to stop the administration of stimulation. 3) The garment should hold desirable qualities when the stimulation is ‘switched off’ to encourage continued wear so that it is easier to re-apply the stimulation again later in the day, for example. 4) It may be useful to control the stimulation parameters too (within a given range), that is suited to the wearer’s needs. This may be achieved independently, via a closed-loop method integrating EMG sensors. 5) Clinicians suggest that it would be useful to monitor the device’s functionality remotely. Participants also questioned whether data could be gathered from the device to inform muscle activity and therefore recovery. This may help to build trust in the device, giving the wearer and clinician a level of visibility towards muscle response.
Aftercare	1) Antibacterial yarn (Samples 39 - 44, Chapter seven) may be used to support long-term use, contributing anti-odour properties. 2) Although the colour of the garment is highly oriented around personal preference, participants resisted white colours since it presented a *“sterile, hospital feel”* (FF, 2019) and is “more likely to look worn and discoloured when worn for a long time” (DD, 2019). 3) Instead, a black yarn was preferred due to its “timeless” (AC, 2019), “slimming” (AA, 2019) and “practical” (SS, 2019) appeal.

Figure. 9.3 (Half) Toile 1: Long sleeved basic jumper
(Author’s archive)

Figure 9.4 Toile 2: Integrated bra 1
(Author's archive)

Figure 9.5 (Half) Toile 3: Integrated bra 2
(Author's archive)

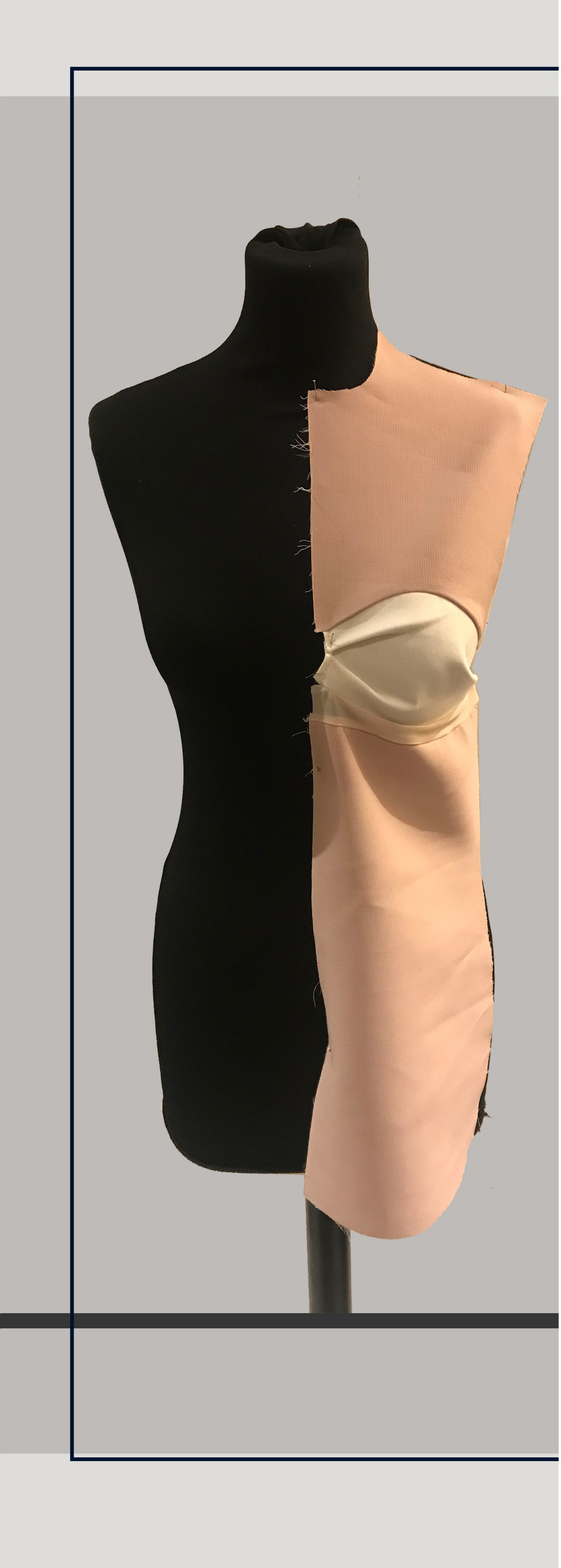


Figure 9.6 (Half) Toile 2: Integrated bra 3
(Author's archive)

FRONT OF BODY.

Raised to si

The following annotations from observations identifying multi-directional stress points is in line with literature findings (Chou et al., 2018). Areas such as the elbow* has been regularly identified and used in the literature as an areas which is harvests energy effectively (Ponnamma et al., (2019b)**. However, other areas such as the underarm area*** and shoulder/ cross-body area are also observed to provide substantial input.

**It should be noted that the amount of movement in each limb varies from individual to individual post stroke.*

***The degree of gathering and stretching in the underarm point varies in directions of reach, whereas there is less difference noticed in the elbow point.*

****It may be equally important to note that these areas receive more subtantial 'wear' and so whilst it can be stated that these areas are useful for energy harvesting the durability of the yarn and textile structures should take this into account.*

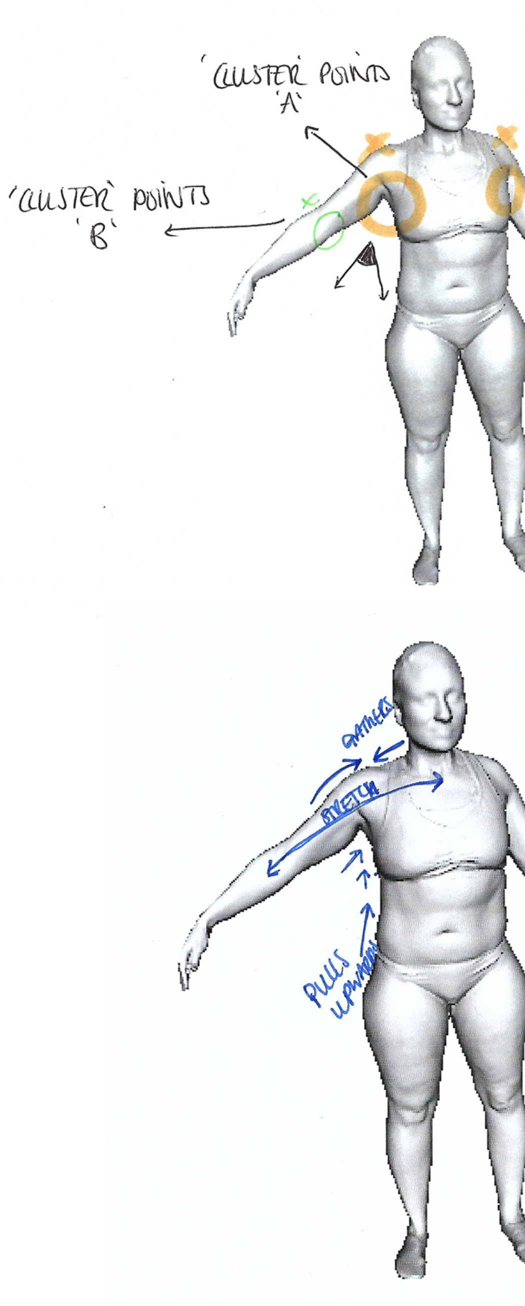
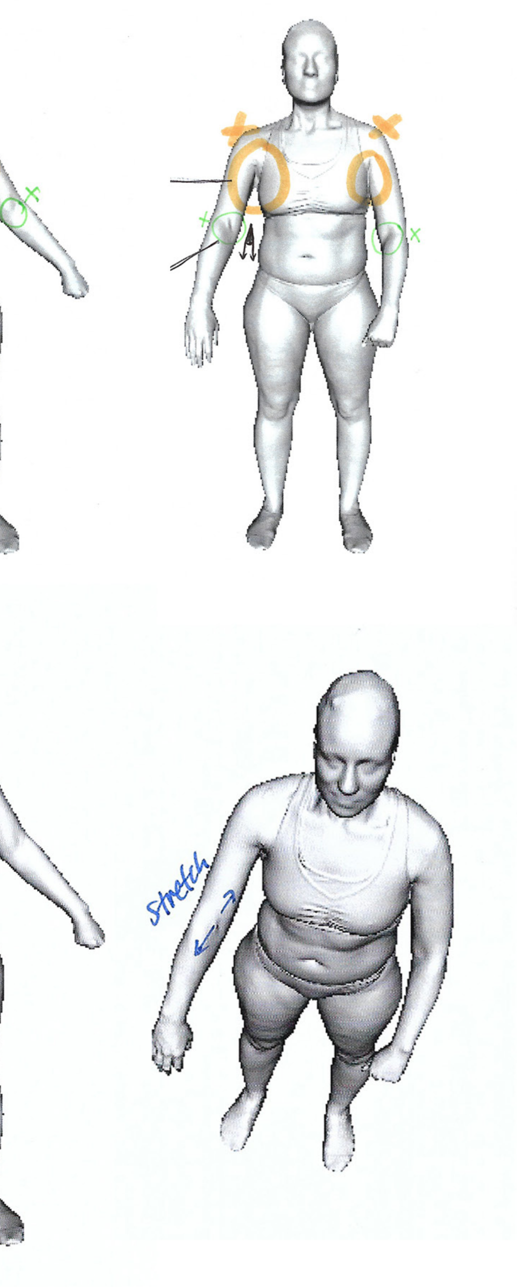


Figure. 9.7 Considering the placement of energy harvesting yarns in the garment: annotated body scan images 1

de

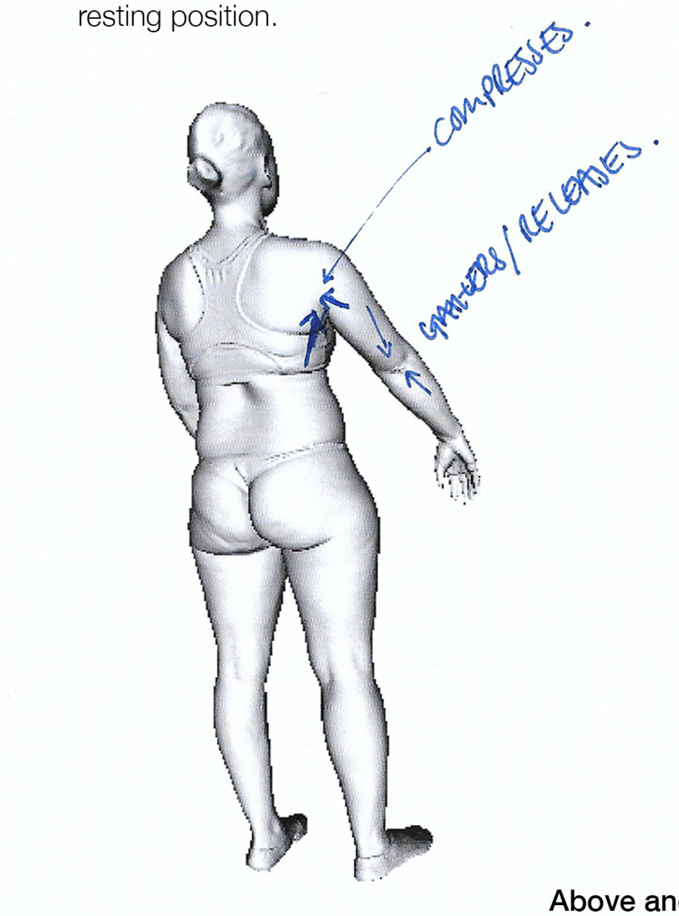
Raised forward



BACK OF BODY.

Right: Front and back 'birds-eye' perspective: note significant increased movement in unaffected upper limb

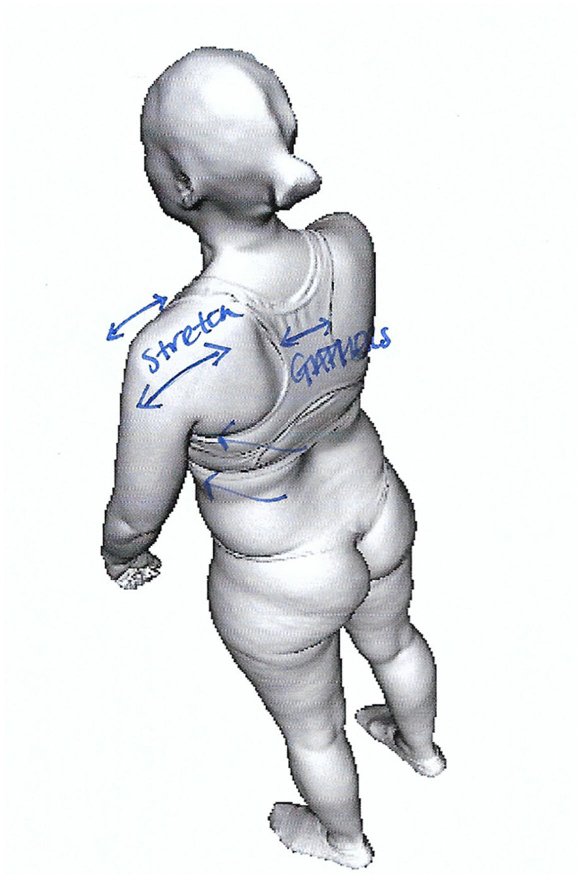
Below: The sleeve becomes compressed and clustered at the under arm point as the limb is lowered. The gathers at the elbow point also begin to release and become increasingly stretched as the elbow bends and the limb takes a resting position.



Above and left: S
point when upper
stretches garment

Figure. 9.8 Considering the placement of energy harvesting yarns in the garment: annotated body scan images 2

Sleeve gathers at rear elbow
limb is extended and
t when limb is retracted.



Above: Depending on the level of fit to the body the garment stretches to a limited degree as a result of the expansion of the ribcage during inhalation and exhilation, however this is not significant enough to sufficiently support energy harvesting applications*. The rotation and retraction of the shoulders** may however be useful to increase the overall degree of energy harvested when combined with energy harvested from the elbow point.

**Although harvesting energy from respiration has shown promise with films (Mhetre and Abhyankar, 2017; Sun et al., 2011)*
***Also consider contact made when a) sat in chair (areas of the garment compressed on the back albeit not cyclic and*
b) arm is rested on surface (elbow point or forearm)

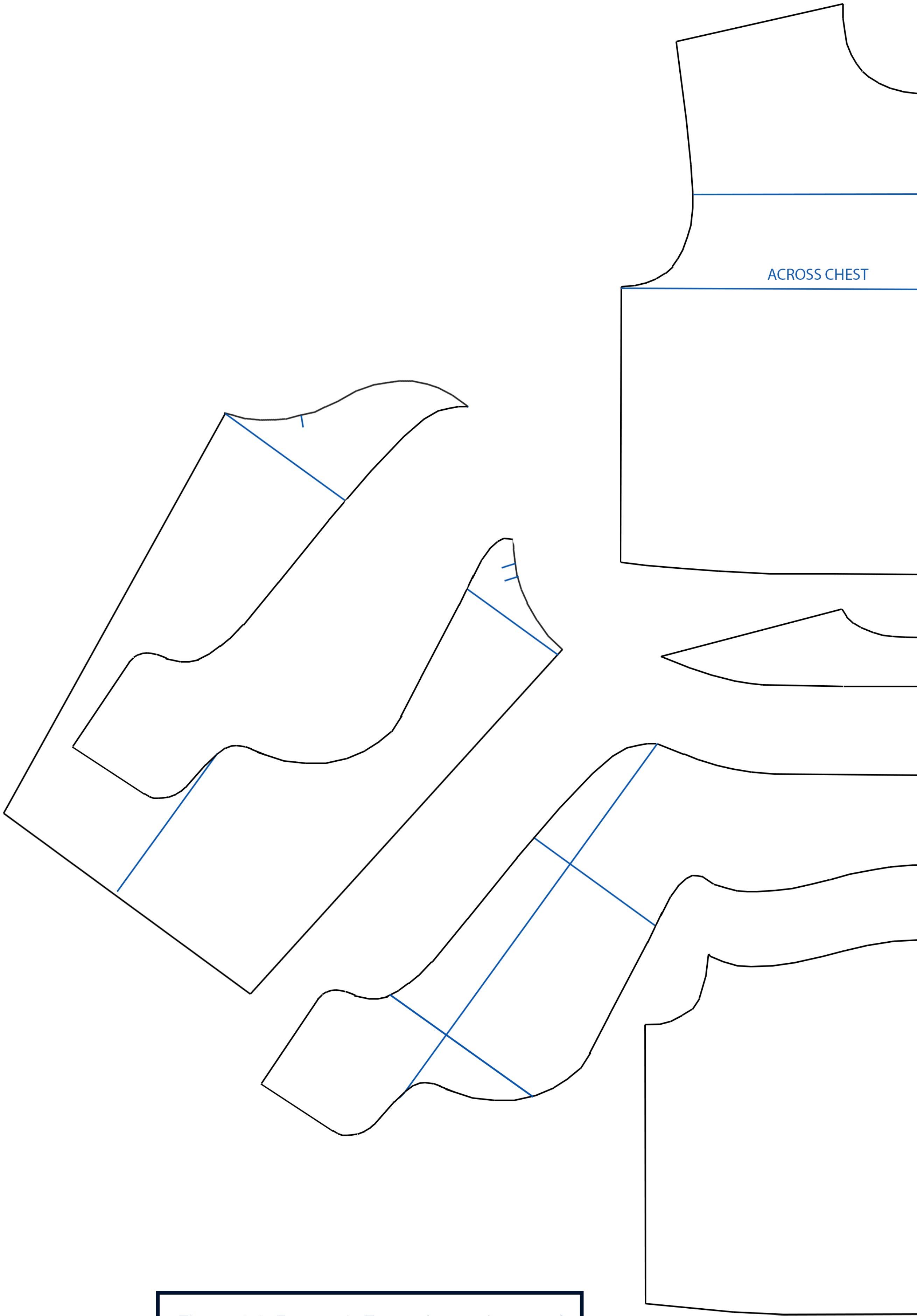
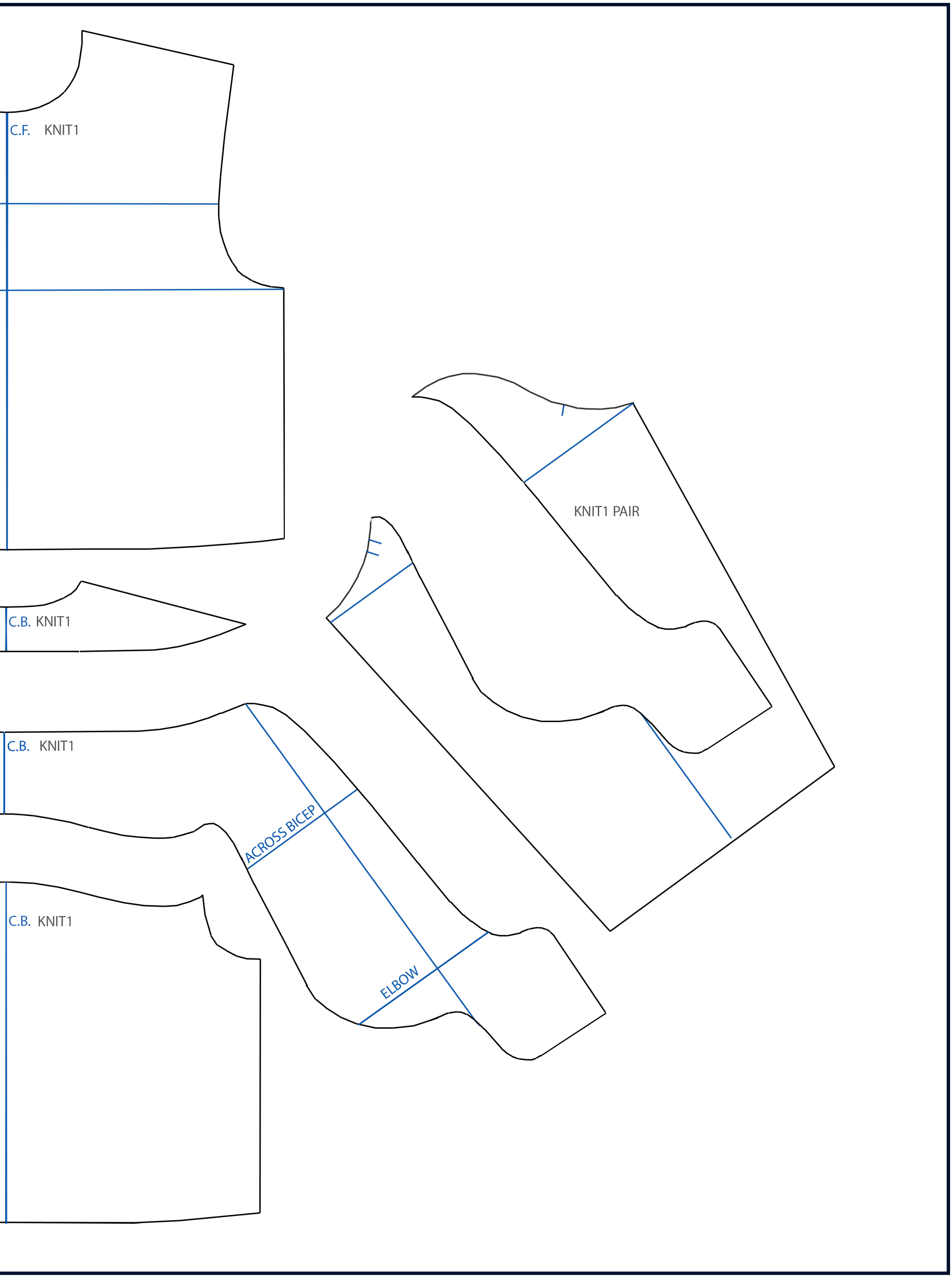


Figure. 9.9 Pattern 1: Energy harvesting panels


C.F. KNIT1
C.B. KNIT1
KNIT1 PAIR
C.B. KNIT1
ACROSS BICEP
ELBOW
C.B. KNIT1

[The following figure that appeared in the thesis was redacted due to its commercially sensitive nature.
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Figure. 9.10 Pattern 1: Considering component positioning

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Figure. 9.11 Considering access to arm for regular hospital procedures [if the affected arm is needed]

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Figure. 9.12 Demonstrating the pattern construction
(Author's archive)

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Figure. 9.13 Paneled t-shirt (Author’s archive)

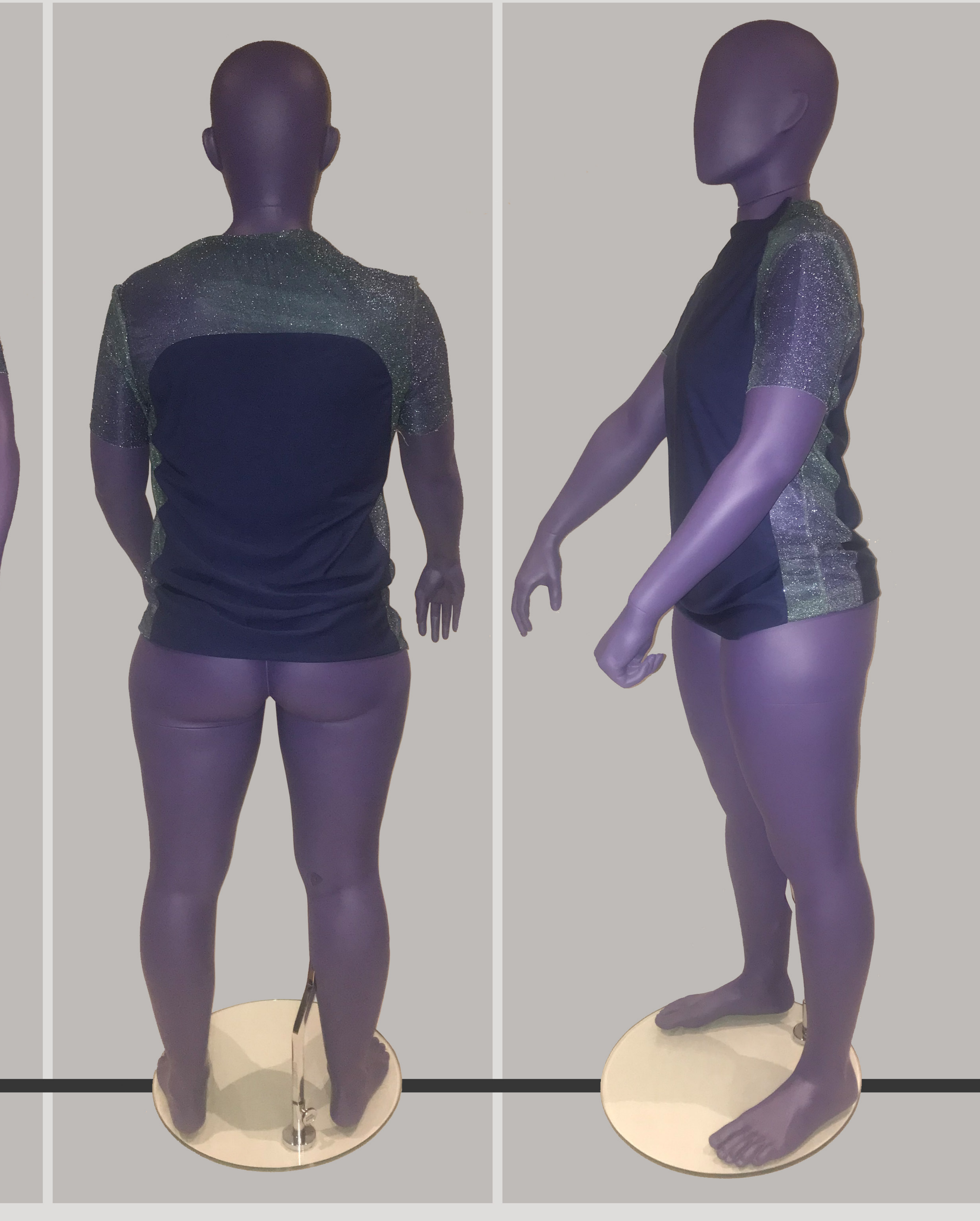

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Figure. 9.14 Graphical representation of a paneled jumper (Salisbury n.d. [b])

Technical investigations 9.3

9.3.1 Knit

In response to findings collated from throughout this PhD, a garment has been constructed in the form of a long-sleeved round-neck jumper. The sample includes a considered distribution of conductive tracks (points c on Figure 9.17) to collect ambient energy produced by body kinesis and a sample textile sensor (point b on Figure 9.17). The sleeve is considered firstly in Table 9.18, before the bodice is later developed (Table 9.20).

The garment represents an example of ‘unapologetic’ (Pullin, 2017), everyday essential wear; a garment that can be worn without attracting stigma, acting as a base for which other garments can be added to, forming an outfit. Unlike with styled garments, where there exists an infinite amount of possibilities, some which are more limited to ‘trends’ than others, the basic, essential wear provides a garment that works with the changing trends and identity of the wearer.

Having said this, even with essential wear, there exists a range of variables that appeal to some more than others; e.g., neckline, fiber content, fit and colour. The priority is the wearer’s comfort within recovery; comfort in the sense of self/ body image, and comfort during wear. Although there is much to explore (Figure 9.3), the garment represents current findings, scaling up Sample thirteen (Chapter seven).

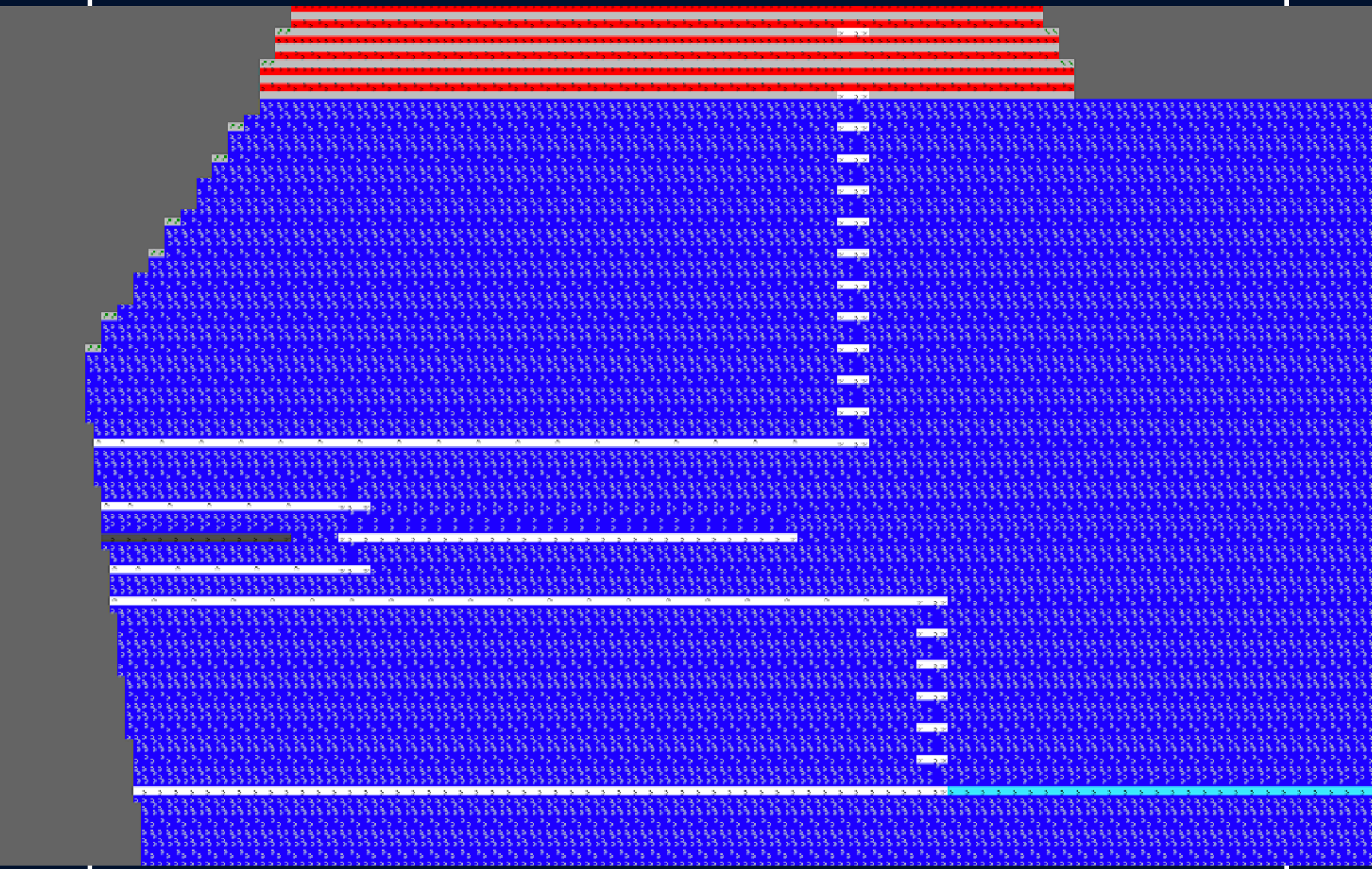
Where Hypothesis 1.0 works on the basis of harvesting energy from body kinesis, Hypothesis 2.0 does not. Therefore, Hypothesis 2.0 does not require the integration of PVDF nor conductive tracks throughout the garment, reducing the garment complexity; experiencing fewer restrictions of textile structure choice that Hypothesis 1.0 does. The final garment incorporates such additions in order to simultaneously address Hypotheses 1.0 and 2.0.

Table 9.15 demonstrates key insights during the making process, with technical data placed in Table A2.64 (Appendix 2.6).

Table 9.15: Key insights and considerations from the sampling of a basic jumper

Sample code	Respective pattern piece	Key insights/ considerations
S T	Sleeves	Yarn breakage was observed when the sleeve head was shaped. Again, the row order was amended in order to overcome this issue; starting on a tubular row for the racking, rather than the inlay.
W		1) In line with Hypothesis 1.0, a range of conductive tracks have been integrated into the pattern to extract and carry charge to the 'bead' (point a, Figure 9.17) and 'sensor'[2] (point b, Figure 9.17). 2) Initially, the conductive tracks were knit on every stitch (Sample i, Figure 9.19), with a tension of 10.5. However, there are too many stitches which are somewhat raised from the surface. These could be easily pulled and snagged. 3) Therefore the tracks are knit on every other stitch (Sample ii), with a partial float. Still, the tracks appear too loose. 4) Sample iii reverts back to knitting every stitch, but with a tighter tension. The tension change does not seem to make a difference. 5) Sample iv explores knitting every other stitch with a tighter tension. There is some improvement on the uniformity of surfaces across the base and conductive tracks. However, they still do not sit neatly within the base textile structure. 6) A stitch is removed from the structure in the tracks (Sample v). This loosens the tracks even further. 7) The tension was tightened to 8 (Sample vi) and the stitches have been spaced out to knit every other stitch. This structure was used to construct the network of conductive tracks within subsequent pattern pieces.
X	Front Bodice	1) When shaping the front bodice, a binder is added to the neckline and hem as a finishing. There exists some issues with yarn breakage when shaping the neckline (points vii and viii). This is due to racking by two rather than a single row. 2) After checking the fit, amendments are made as follows: a) hem has been reduced by 1.5cm either side; b) underarm point has been taken in by 1cm either side; c) the top of the armhole/ shoulder point has been extended by 1.5cm.
Y		1) In Sample Y, there are issues with the second feeder, when shaping the neckline, which is racking by two rather than one, causing the yarn to break (point vii). 2) For the purpose of connecting the energy harvesting components in each sleeve, a set of conductive tracks were constructed around the neckline (Figure 9.16).
Z	Back Bodice	1) The armholes and neckline are re-shaped; reducing the depth of the neck and armholes which require a shallower shaping to fit accordingly. 2) Conductive tracks (Figure 9.16) were integrated to connect with the tracks on the front and sleeves.

[2] Initially the EMG sensor was decoupled from the bead but, it was later incorporated into the bead (Figure 9.35). However, risks arise from doing so requiring work to: a) reduce noise and interference with the EMG signal from electromagnetic fields; b) and receive adequate signal from a small scaled component.



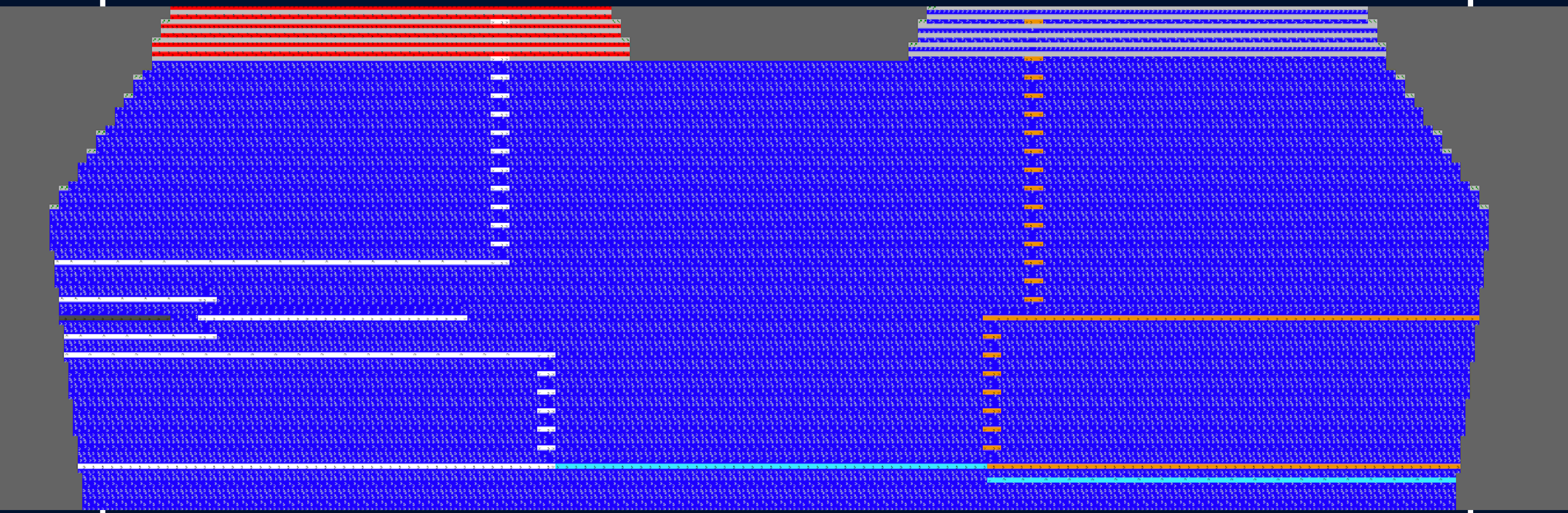


Figure. 9.16 Integrating conductive tracks at the neckline: placement in knit structure

FRONT

BACK

[The following image that appeared in the thesis was redacted due to its commercially sensitive nature.
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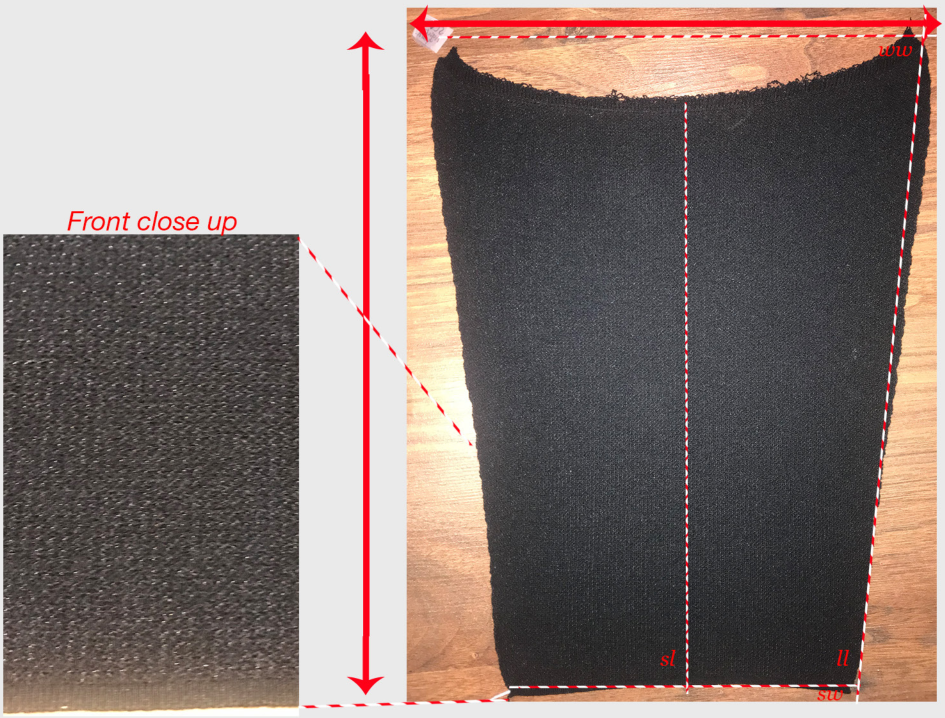
SLEEVE

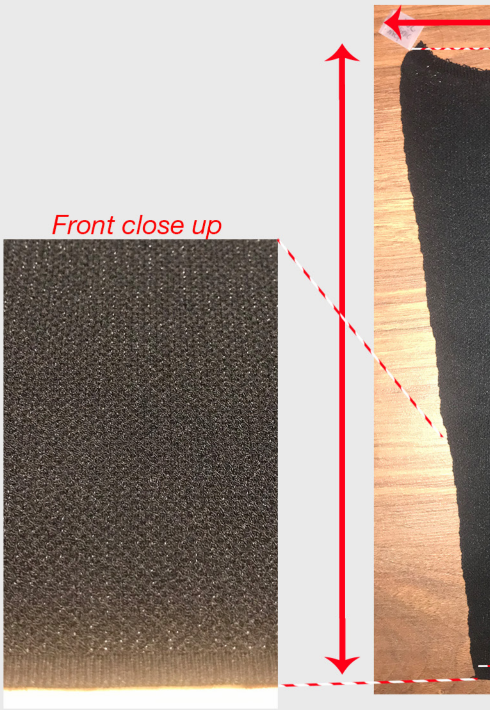
Figure. 9.17 Bead Concept 1.0: Integrating conductive tracks: inside of garment (a) Float stitch for attaching the Bead; (b) Knitted textile sensor; (c) Conductive tracks; (d) Positioning of textile switch [and microcontroller in Hypothesis 1.0]. (Salisbury, n.d. [b]; Author's archive)

SAMPLE **S. Interlock Spacer**



Widest width (ww): 31.5cm *Shortest width (sw): 21cm*
Longest length (ll): 40.5cm *Shortest length (sl): 35.5cm*

SAMPLE **T. Interl**



Widest width (ww): 30.5cm *S*
Longest length (ll): 41cm *Sh*

lock Spacer

Shortest width (sw): 21cm
ortest length (sl): 36.5cm

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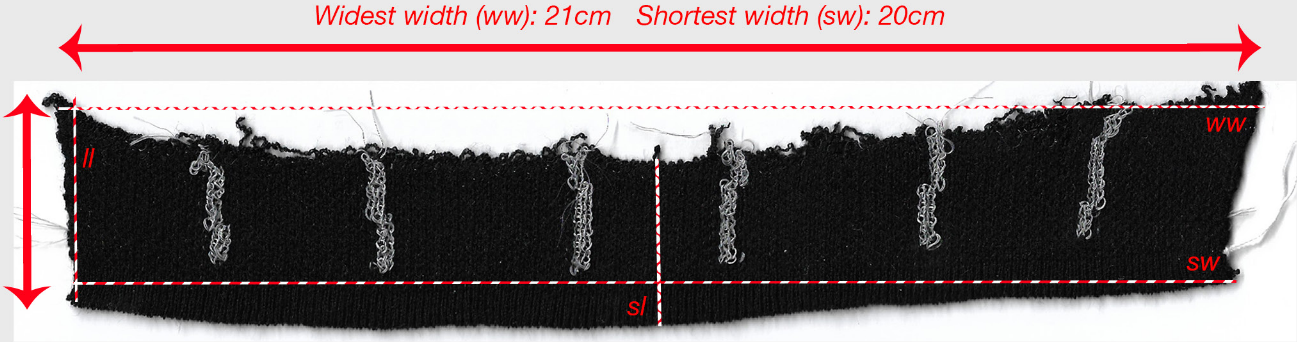
Figure 9.18: Scaling up samples: The Sleeve (Author’s archive)

SAMPLE **i. Interlock Spacer with Tracks**

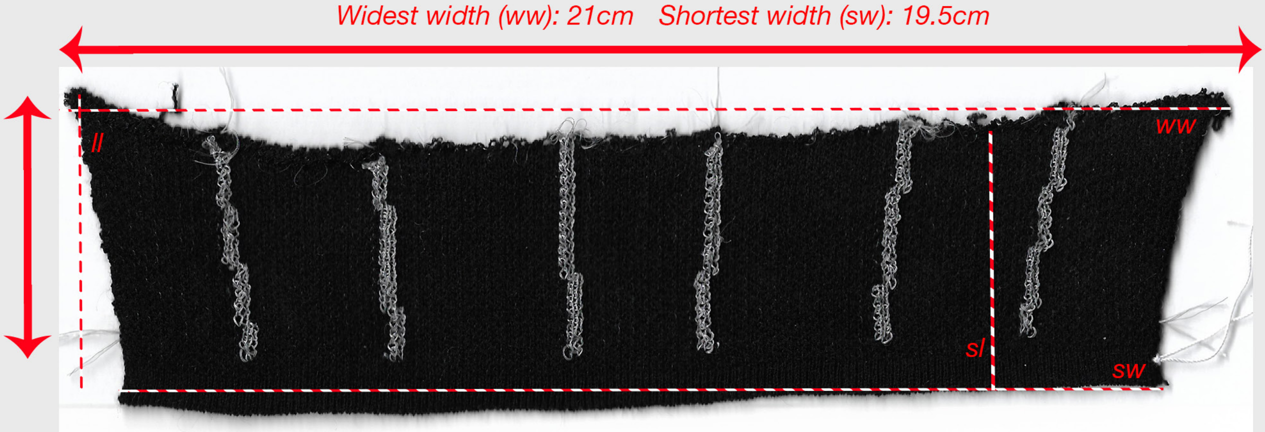
Widest width (ww): 21cm Shortest width (sw): 20cm



Longest length (ll): 3.5cm
Shortest length (sl): 2.75cm

SAMPLE **iii. Interlock Spacer with Tracks**

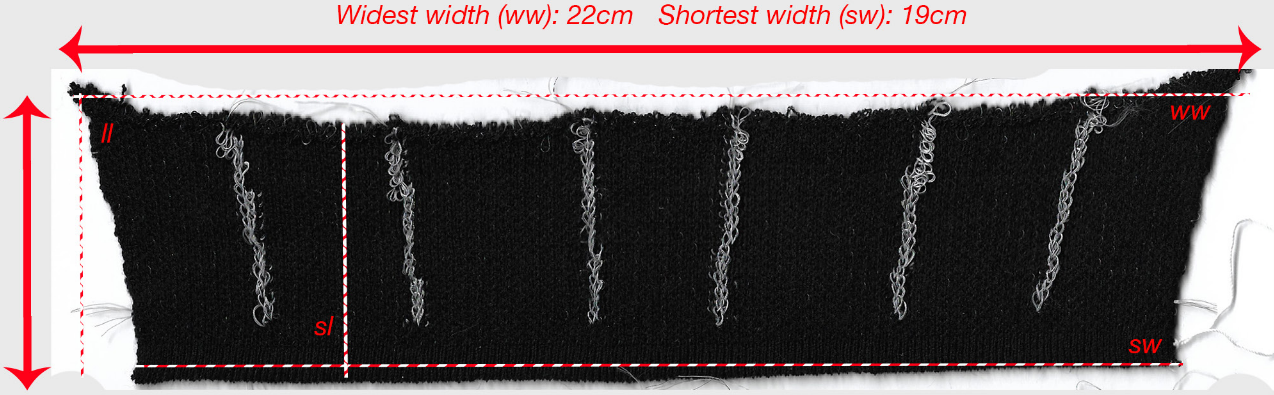
Widest width (ww): 21cm Shortest width (sw): 19.5cm



Longest length (ll): 5cm
Shortest length (sl): 4cm

SAMPLE **v. Interlock Spacer with Tracks**

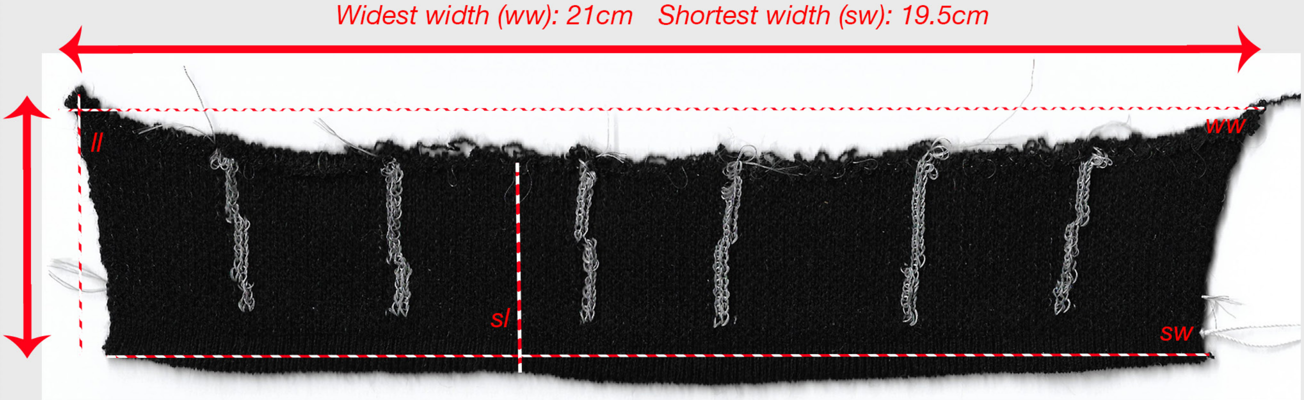
Widest width (ww): 22cm Shortest width (sw): 19cm



Longest length (ll): 5.5cm
Shortest length (sl): 4.75cm

SAMPLE **ii. Interlock Spacer with Tracks**

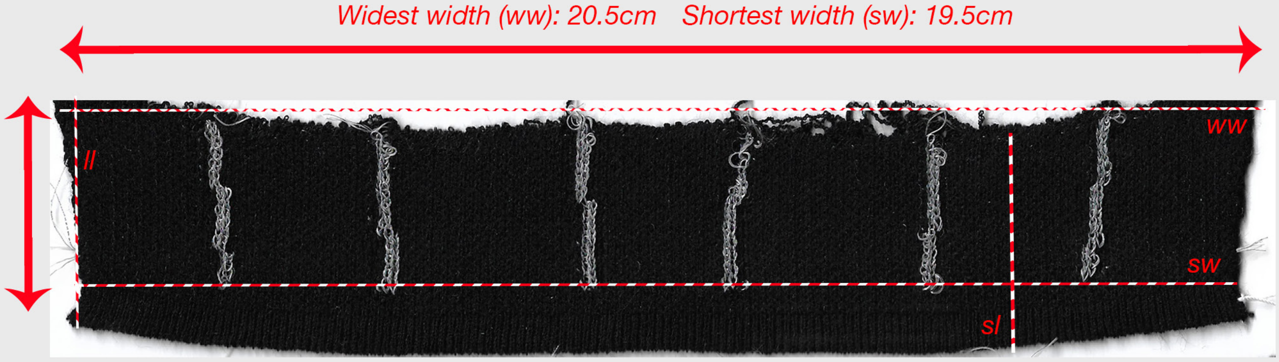
Widest width (ww): 21cm   Shortest width (sw): 19.5cm



Longest length (ll): 5cm
Shortest length (sl): 3.75cm

SAMPLE **iv. Interlock Spacer with Tracks**

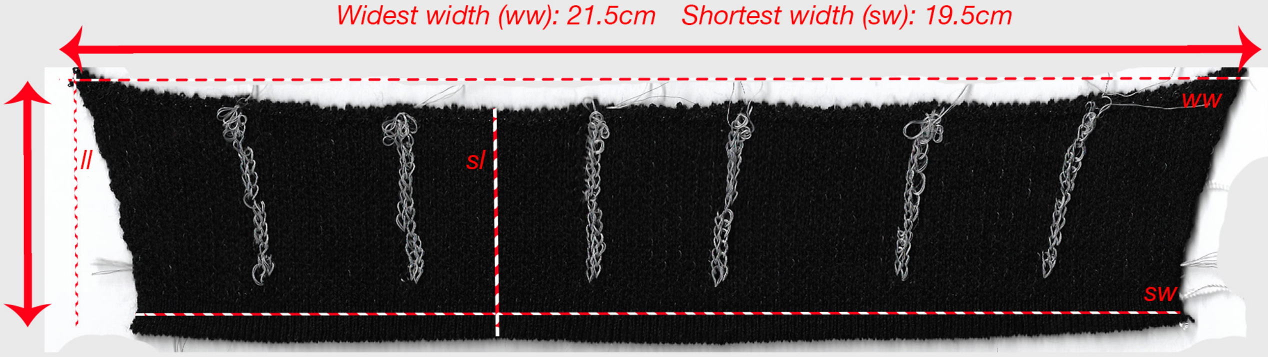
Widest width (ww): 20.5cm   Shortest width (sw): 19.5cm



Longest length (ll): 4.5cm
Shortest length (sl): 3.75cm

SAMPLE **vi. Interlock Spacer with Tracks**

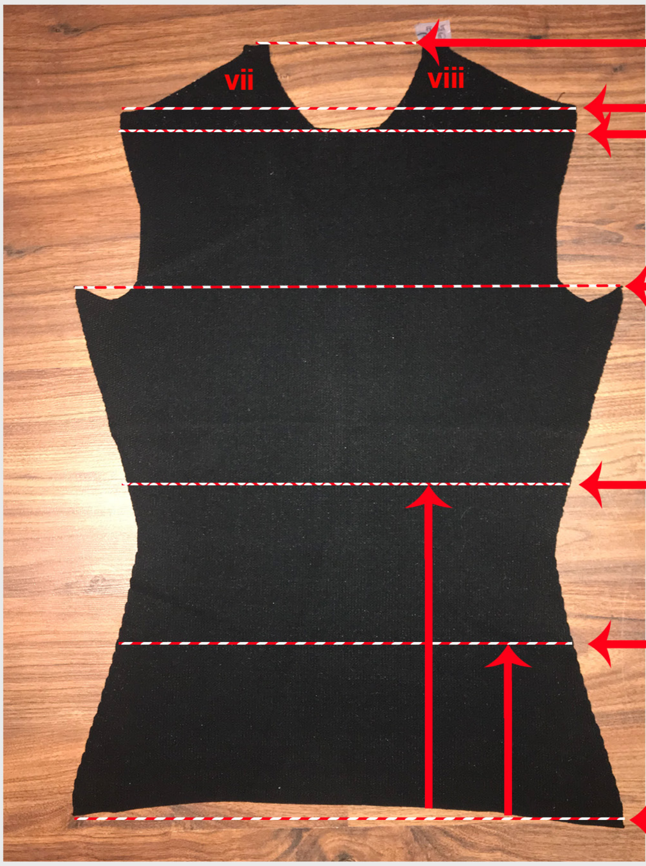
Widest width (ww): 21.5cm   Shortest width (sw): 19.5cm



Longest length (ll): 5cm
Shortest length (sl): 4.5cm

Figure 9.19: Scaling up samples: Integrating conductive tracks (Author's archive)

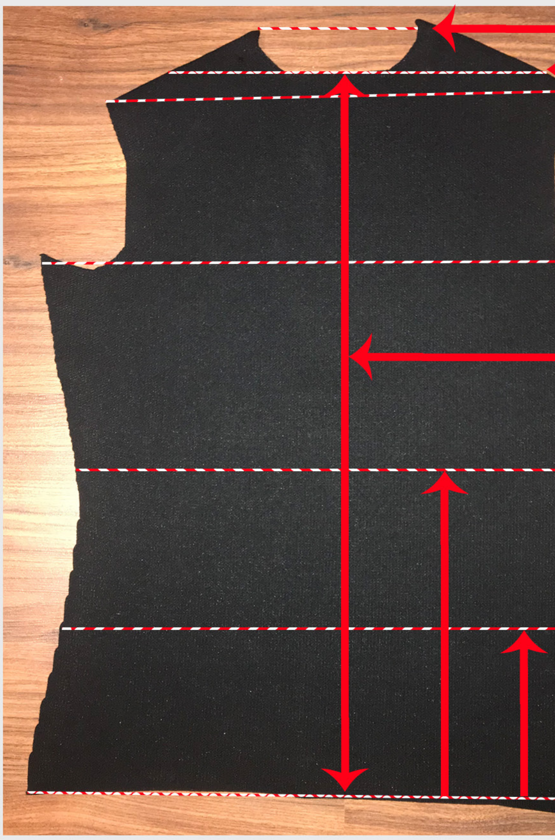
SAMPLE **X. Interlock Spacer**



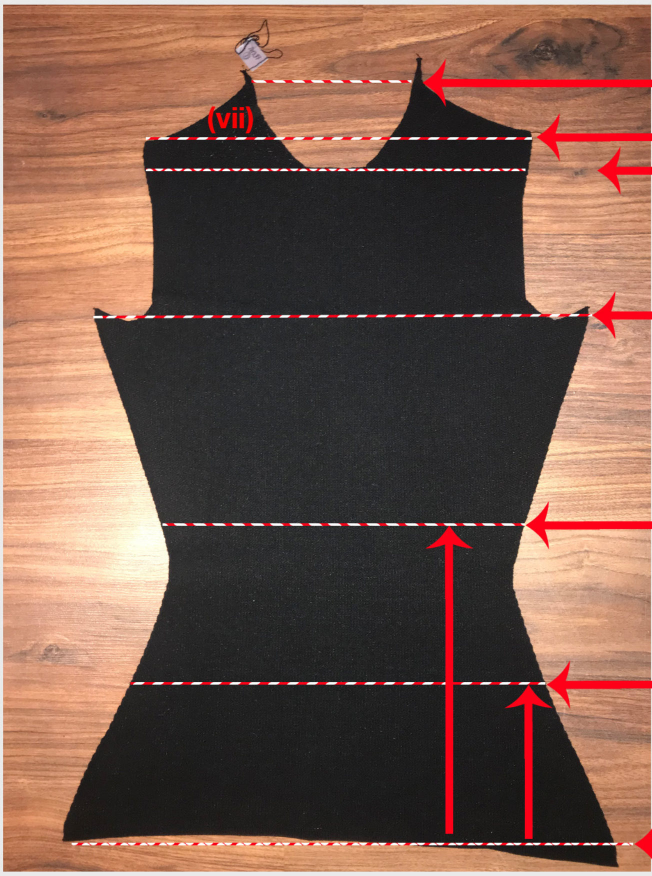
	Before pressing:	***After Pressing:***
	16cm	14cm
	46.5	42.5
	47	43
	54.5	50
	44cm (25cm from base)	41
	47cm (10cm from base)	43
	51.5	46

Close up of points vii and viii

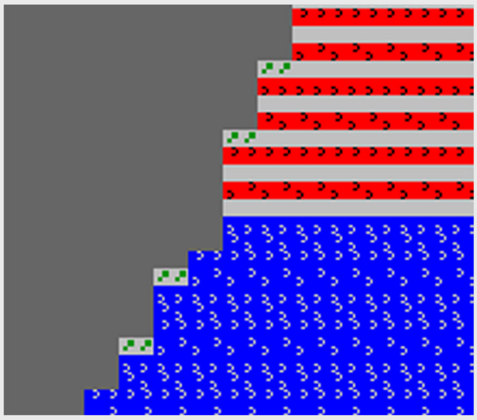
SAMPLE **Z. Inte**



SAMPLE **Y. Interlock Spacer**



Before pressing:	***After Pressing:***
16cm	14cm
46.5	38.5
47	38
54.5	48
44cm (25cm from base)	41
47cm (10cm from base)	43
51.5	47



Shaping

rlock Spacer

Before pressing:	***After Pressing:***
15cm	13cm
29.5	24.5
40.5	37.5
49	45.5
70 (length down centre front)	60
42.5cm (25cm from base)	40
46cm (10cm from base)	44
52	48

Figure 9.20: Scaling up samples: The Bodice (Author's archive)

9.3.2 Pattern considerations

The set in sleeve pattern used to construct the prototype garment (Figures 9.31 and 9.36) presents issues of lost energy at the seams where the garment is linked. The connection of two separate conductive yarns likely leads to the generation of heat spots. Figure 9.21 demonstrates the prevalence of heat spots in a test sample where two separate Inox yarns have been re-connected together. Reducing energy loss is important in this particular case, where energy harvested can be low.

In response to this, a new pattern has been drafted (Figures 9.22 and 9.23). The pattern retains the 'familiarity' of the common set-in sleeve, whilst enabling a continuous conductive yarn to be maintained by blending the sleeve to the shoulder at the sleeve head (annotated 'dis', Figure 9.23). The final patterns are included in Section 9.4.

Figure. 9.21 Detecting heat spots in cut and reconnected conductive yarn (Author's archive)

Joining shoulder seams: Slash and spread 50:50

- If slash and spread all volume into the front or the back, the garment will become unbalanced. Therefore distribute 50% of the fullness into the front and 50% into the back bodice when joining both shoulders.

i. Front volume redistribution: Slash and spread

- Cut along front cut line (**fcl.**) and across mid line (**ml.**). Pivot to join front shoulder seam (**fss.**) to mid line point, opening up space in front bodice (see **iii.**)

ii. Back volume redistribution: Repeat (**i.**) in back bodice

- Pivot remaining space (**bss.** to **ml.**) to back bodice to close shoulder seams together (**vi.**)

iii. New front bodice volume: Shoulder seams closed, thus opening up volume in bodice

- Consider amount of volume here. Is this excessive? To adjust the fit, reshape side seams (**v.**)

iv. Reshape panels: Ensure the panel/ shape lines make sense

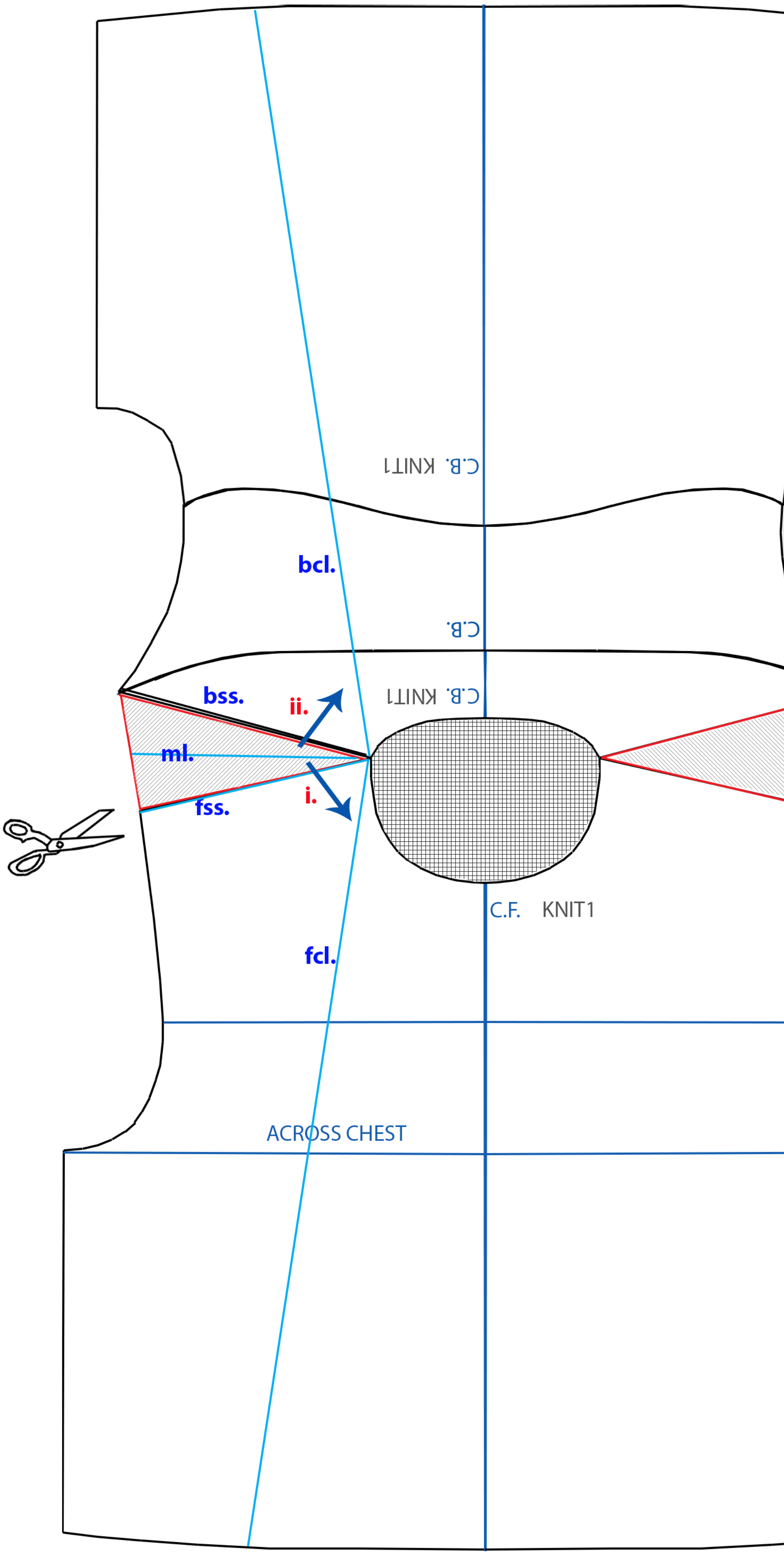
- due to change in volume of bodice, shaping may need to be re-considered, especially if integrating a bra. Consider reshaping side seams, armholes and hem to adjust accordingly so correct fit for integrated bra can be obtained

v. Reshape for closer fit: Side seams reshaped according to fit requriements

- blend and re-shape armholes if needed

vi. Close shoulder seams: Match together front and back shoulder seams

- Ensure the lengths match



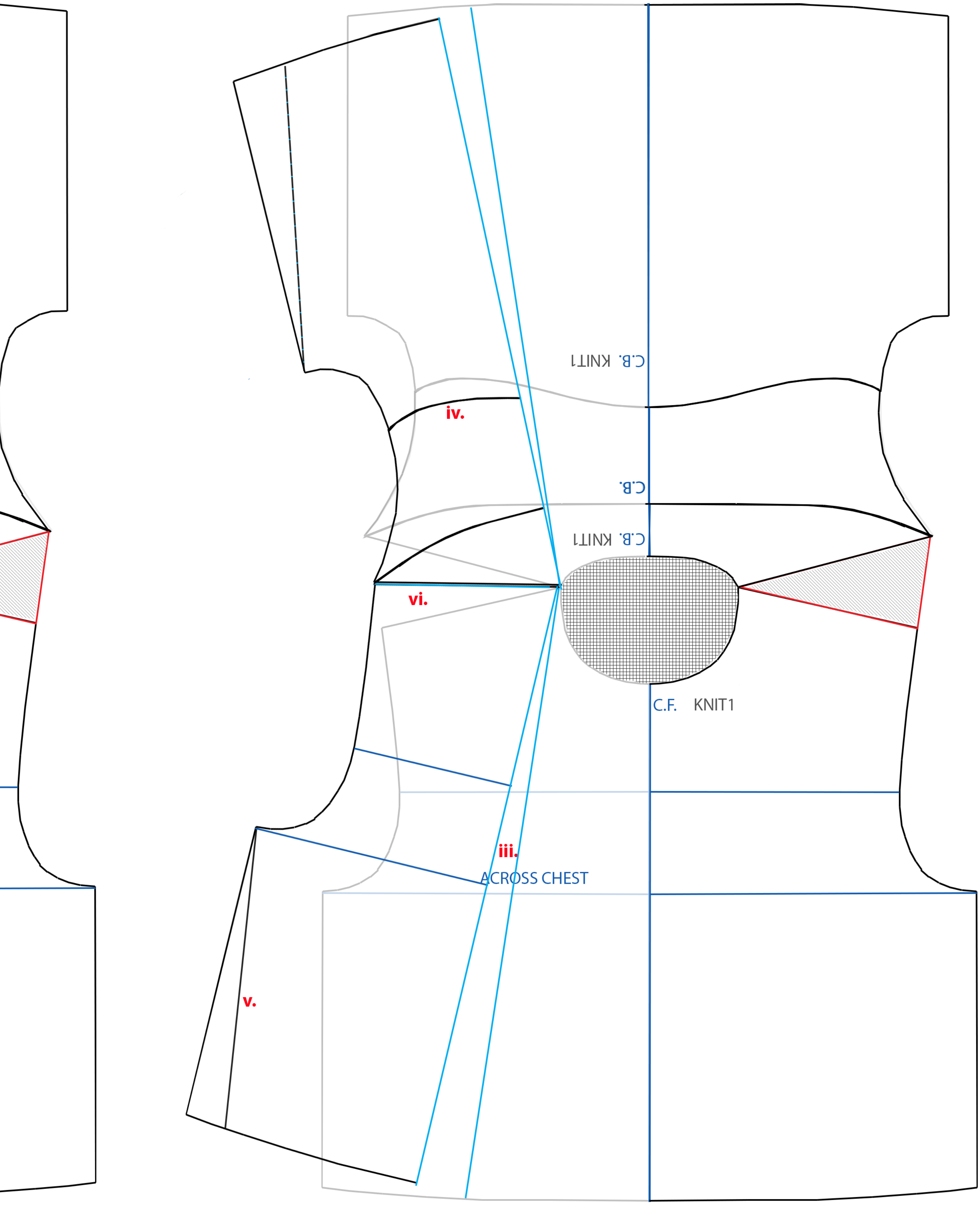


Figure. 9.22 Final pattern development: Step 1 (Salisbury, n.d. [b])

i. Gradient of curve during blending
: Consider shape

- The quality of shaping of the shoulder and seamless blending of shapes is highly dependent upon the shape of the join line. Consider this as a dart, therefore using a sharper point to join rather than a curve. This also improves accuracy.

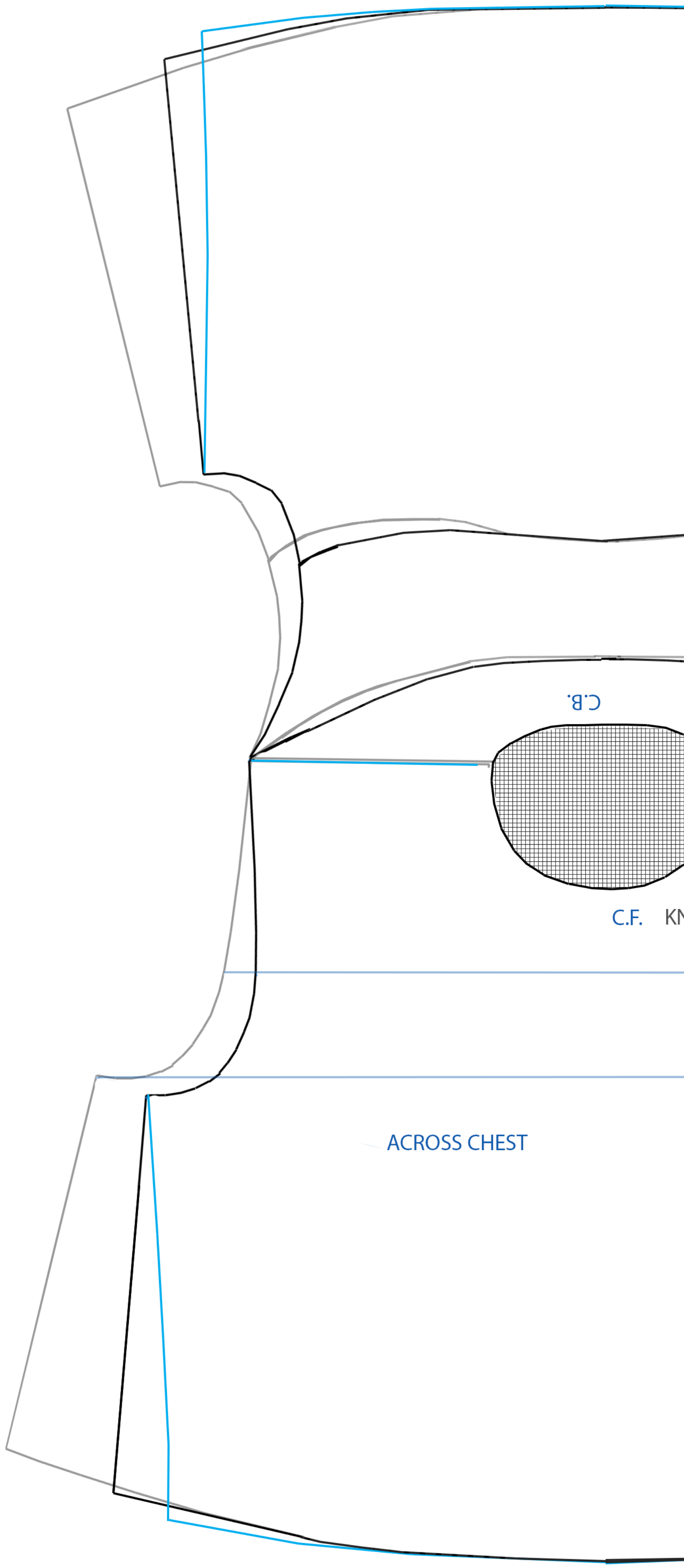
ii. Matching armhole seams:
Consider length

- Ensure that the length of front arm hole (**fah.**) matches sleeve arm hole (**sah.**)
- Knit in coloured notches to support matching

iii. Merge space: Consider depth

- A shorter distance (**dis.**) reduces the amount of space within which conductive yarn can be directed through, affecting placement of yarn and (perhaps) output performance.]

-Yet a larger distance affects the shaping of the sleeve, contributing to mis-shaping and fit issues.



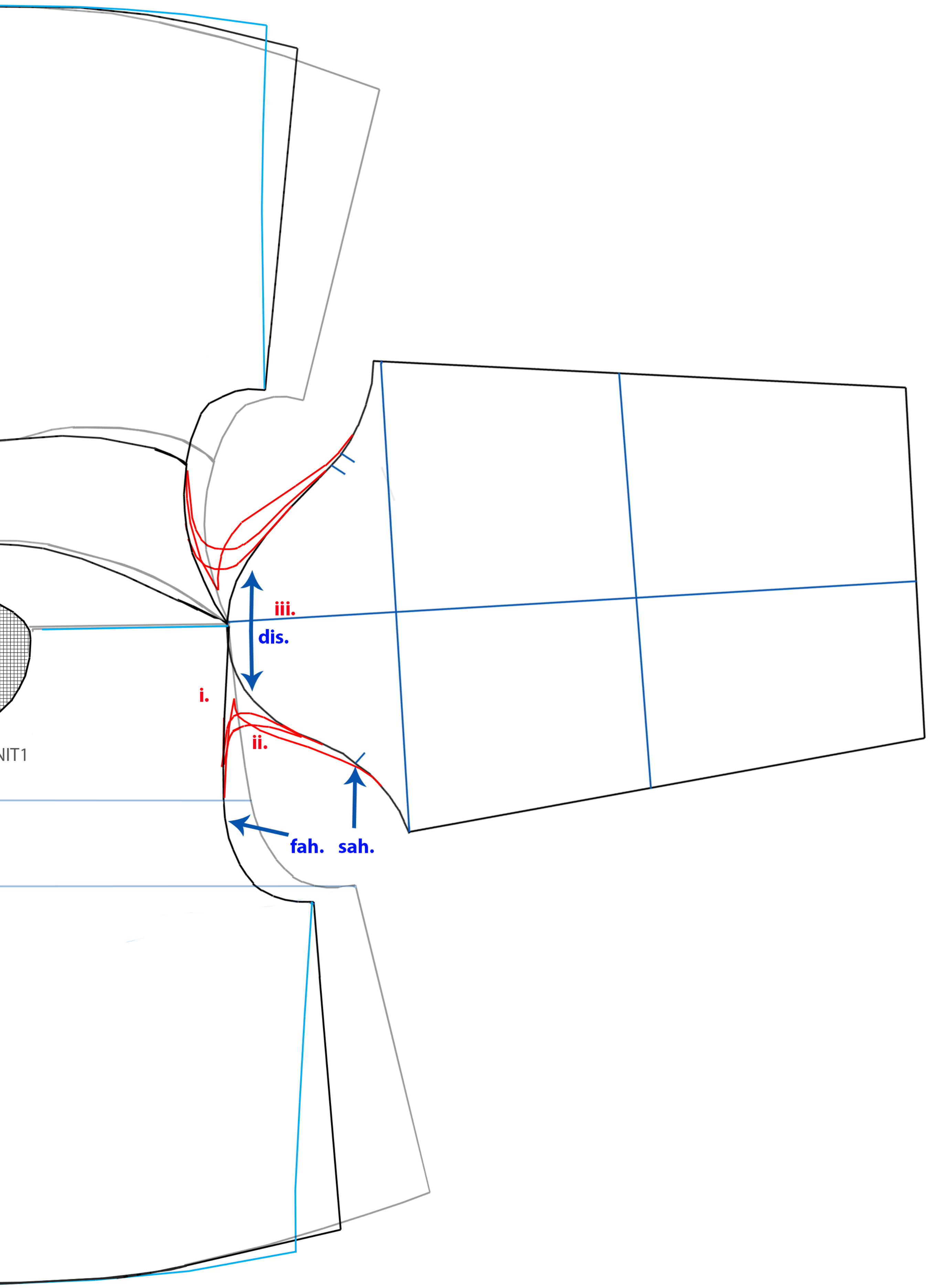


Figure. 9.23 Final pattern development: Step 2 (Salisbury, n.d. [b])

9.4 Final Bead Concepts

To conclude this case study, Bead Concepts 1.0 and 2.0 are detailed below[3]. These represent the culmination of research findings, future opportunity and an alternative perspective towards upper limb care. They provide the foundations for which further work can be built from, translating the research outputs into real-world impact. A diagrammatic illustration of 'Future Work' can be found thereafter in Chapter ten.

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Following this, the chapter concludes with a discussion around the impact of the following factors for using a garment as a therapeutic tool:
a) Role of energy harvesting for powering the device;
b) Considerations for the shape and visibility of the component;
c) The style of garment and seasonal considerations;
d) Garment fit;
e) Considerations for controlling the intervention when wearing the garment.

An overview of the concept which Case Study four is attending to will firstly be introduced (Figure 9.24) before summarising Bead Concepts 1.0, 2.0 and 3.0 and finally, discussions around the above points considering the opportunities and challenges of using a garment as a therapeutic intervention.

[3] The diagrams attend to the left-hand limb. Right-handed versions would require moving the stimuli over to the other sleeve.

Overview of the concept in Case Study 4

Figure. 9.24 A final pictorial summary of the garment hypothesis (Salisbury n.d. [b])

Delivering the stimuli:

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9.4.1 Bead Concept 1.0

The following section includes figures demonstrating the garment (Figure 9.25) representing the arrangement of ‘components’; an overview of the ‘bead’ (Figure 9.26); and the final prototype garment (Figures 9.27 to 9.29). These act as ‘Bead Concept 1.0’ for further study beyond the PhD.

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Figure. 9.25 Representation of component placement and network of conductive tracks within an inside view of the garment. (Salisbury n.d. [b])

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Figure. 9.26 Diagrammatic representation of the bead: Concept 1.0 (Salisbury n.d. [b])

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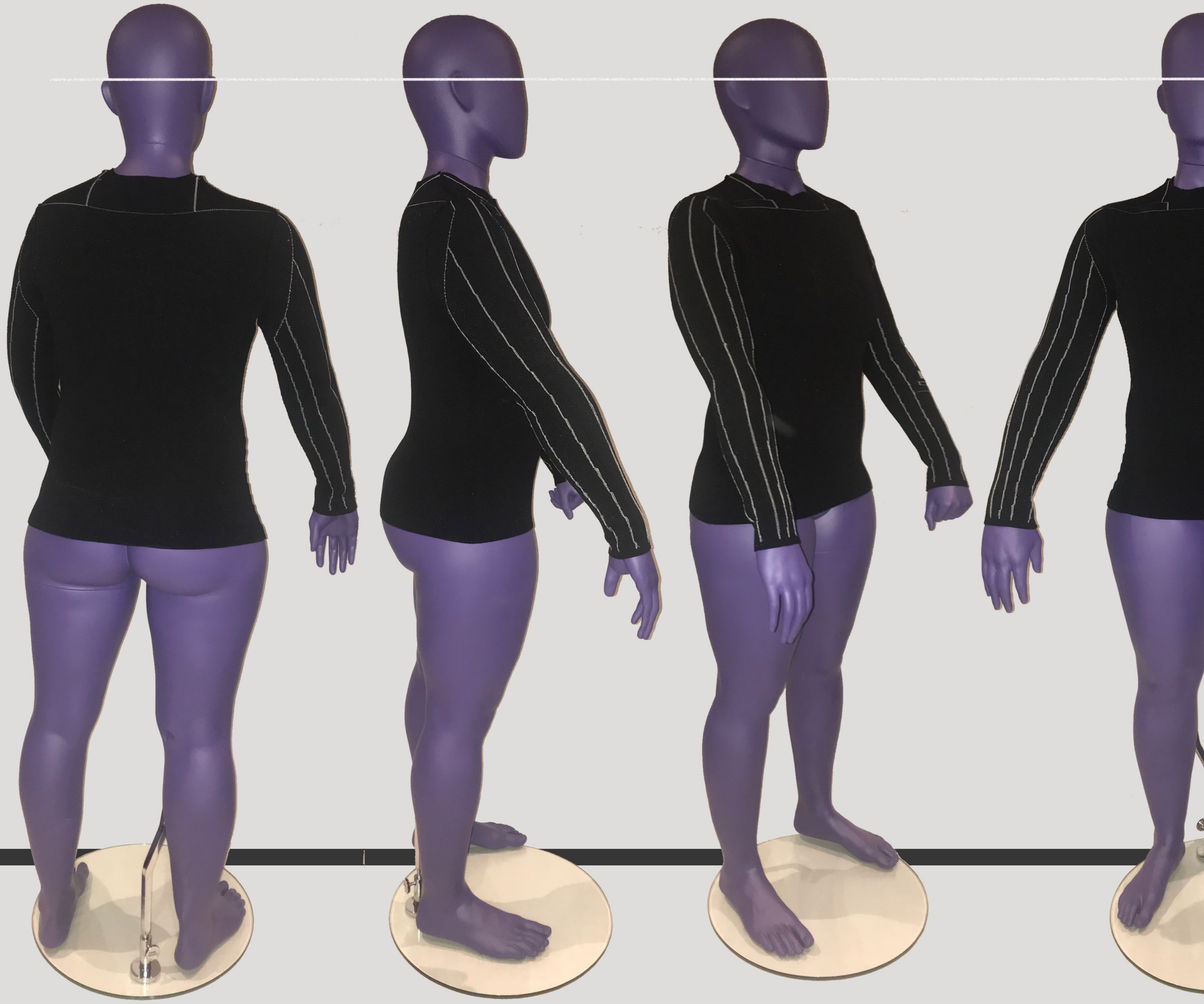

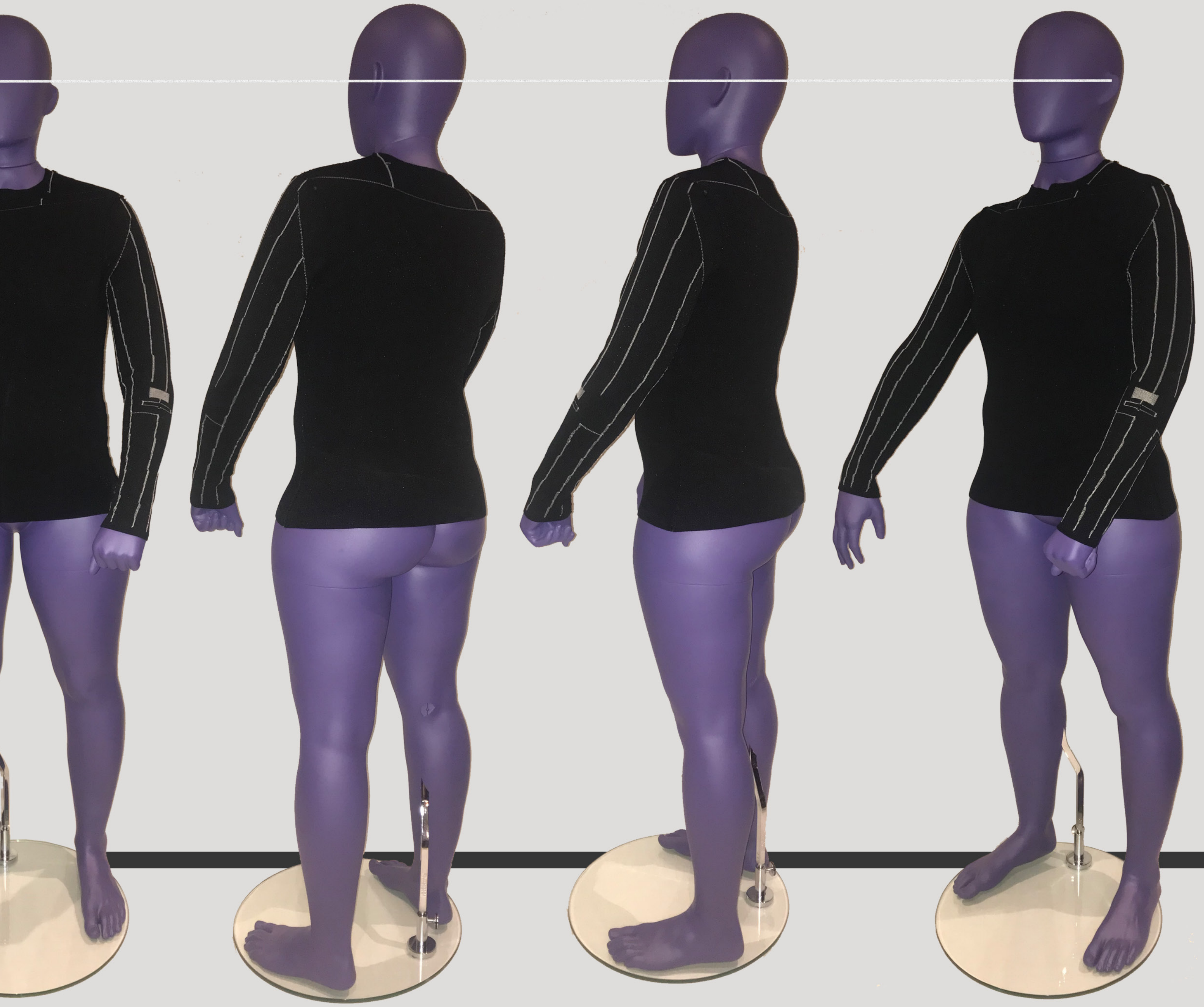

Figure. 9.27 Final prototype: Inside of the garment

Figure. 9.28 Final prototype: Outside of the garment

Figure. 9.29 Final prototype: Neckline close-up

9.4.2 Bead Concept 2.0

This section demonstrates ‘Bead Concept 2.0’ via figures displaying: the garment (Figure 9.30) representing the arrangement of ‘components’; an overview of the ‘bead’ (Figure 9.31); and the final prototype garment (Figure 9.32).

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Figure. 9.30 Representation of bead placement within an inside view of the garment. (Salisbury n.d. [b])

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Figure. 9.31 Diagrammatic representation of the bead: Concept 2.0
(Salisbury n.d. [b])

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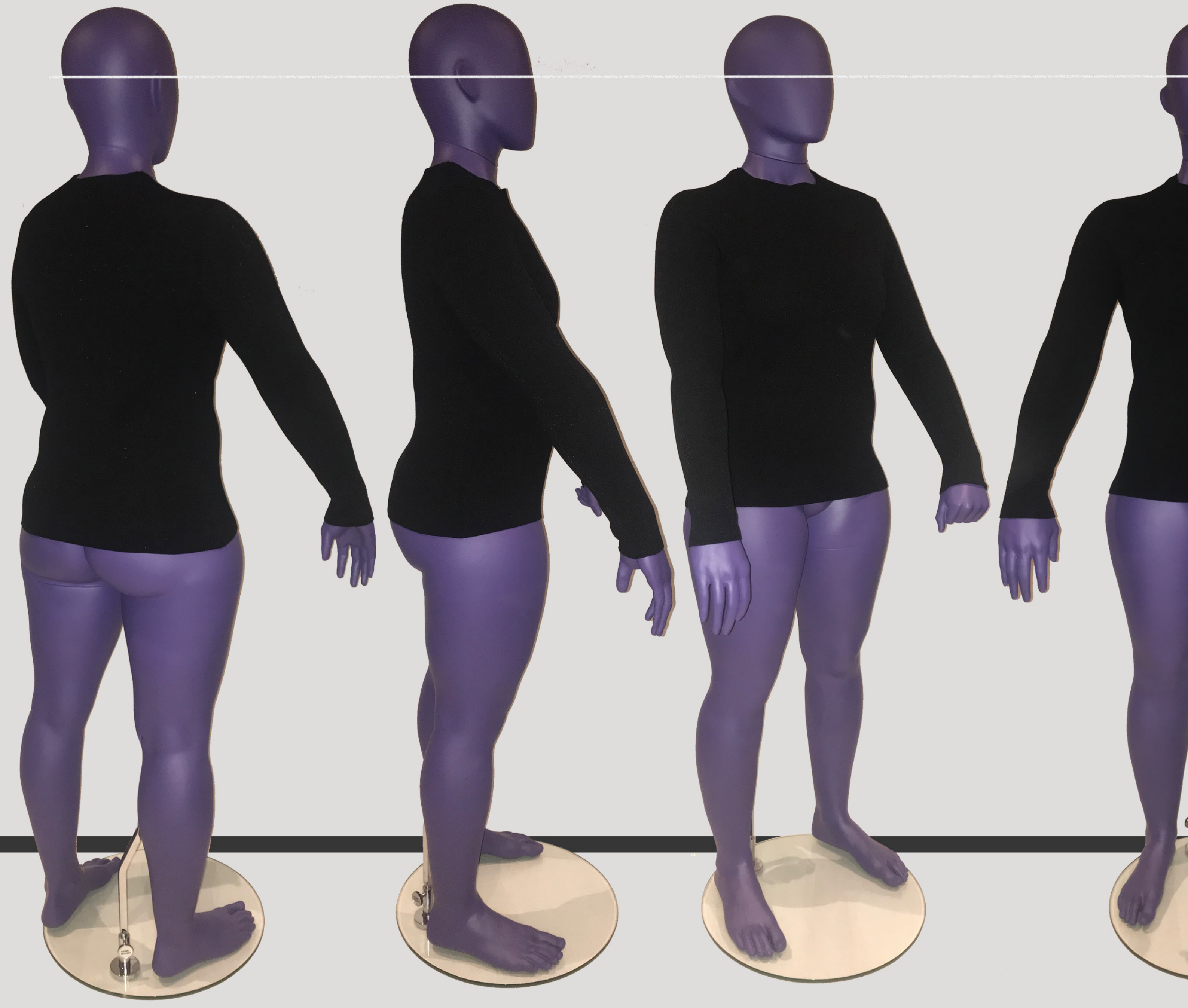

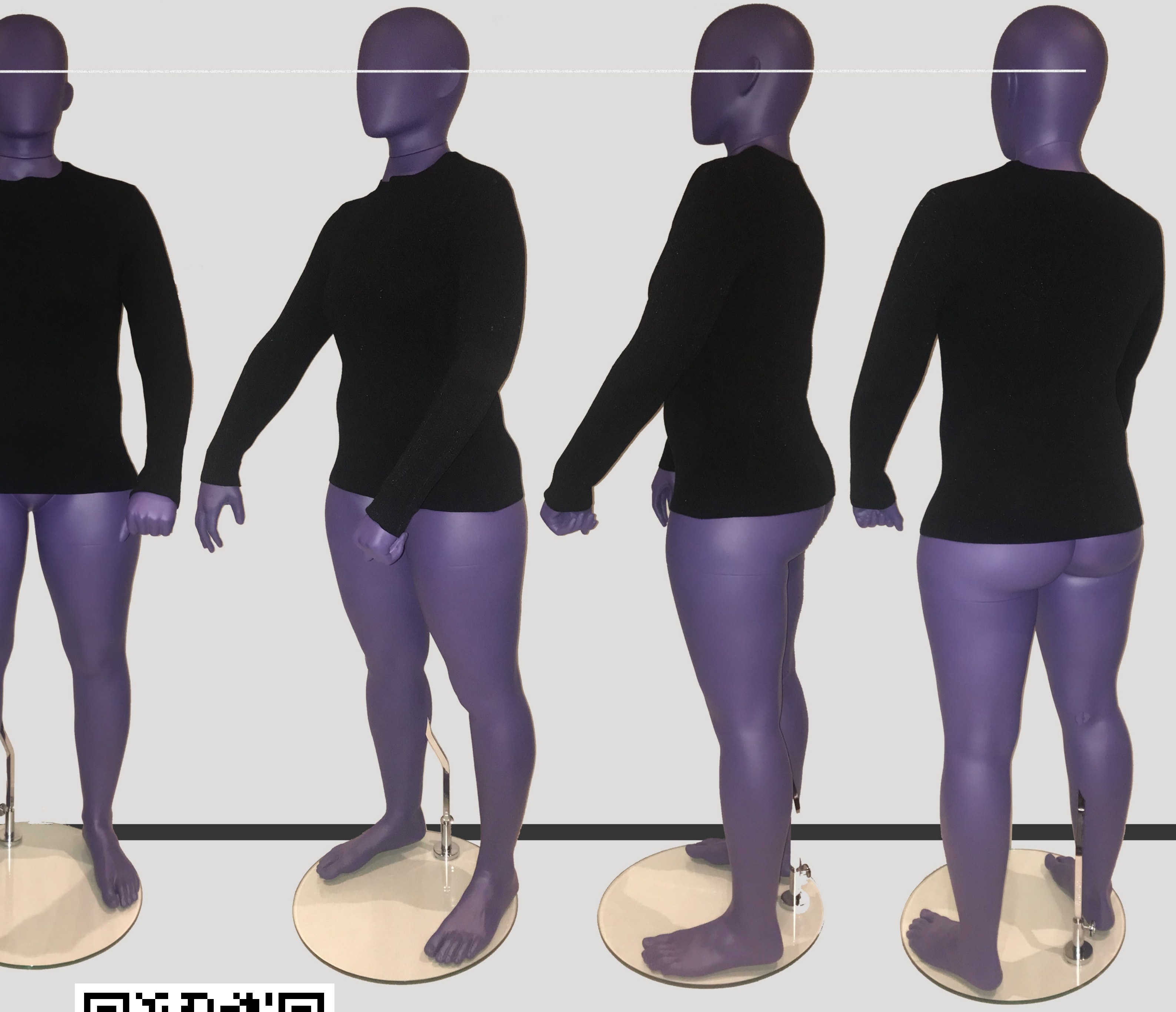

Figure. 9.32 Final prototype

9.4.3 Bead Concept 3.0

This section demonstrates a final concept ‘Concept 3.0’ which acts as a prototype whereby an evaluation can be made for power, force and other component requirements for delivering the stimulation protocol outlined in Chapter five. This is achieved by displaying: an overview of the ‘bead’ (Figure 9.33); and a range of tables (9.34 and 9.35) and calculations.

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Figure. 9.33 Diagrammatic representation of integrating voice coil into bead casing: a) Piston fully enclosed; b) 'Square' piston tip; c) 'Domed' bead head extended view; d) 'Domed' bead head retracted view; e) Perspective shot: 'Domed' bead head integrated into section of sleeve. (Salisbury n.d. [b])

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9.4.3.1 Introducing Bead Concept 3.0

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9.4.3.2 Anticipated power requirements

Working in collaboration with an electronic engineer (Hemmingway, 2021), the following calculations were created to analyse the anticipated power requirement of using a voice coil for the intended application of manipulating muscle spindle responses. It is worth noting that this collaboration also continued into considerations for connecting the components (Section 9.4.3.3), and for supporting discussions around key hazards (Section 9.4.3.4) associated with circuit design with fellow engineer (Wilkinson, 2021).

Table 9.34: Analysis of power consumption versus the size of voice coils to meet the stimulation parameters

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9.4.3.3 Considerations for connecting components

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9.4.3.4 Identifying key hazards of use: Concept 3.0

Finally, an initial, brief risk assessment was conducted in collaboration with independent ISO13485 accredited engineers (Hemmingway and Wilkinson, 2021). A summary of the discussion is collated into the following Table (9.35):

Table 9.35: Safety considerations for using piezo and voice coil Bead prototypes on healthy volunteers

Hazard Type	Hazard	Potential Implications	Potential Mitigations
Mechanical	Bead actuation	Nerve damage	Ensure correct positioning of the Bead, avoiding nerves, and limit the force delivered (account for amount of consistent force that causes nerve damage in detail)
		Ligament damage	Limit force
		Bruising	
		Skin penetration	
	Compression (from textile)	Loss of circulation	Limit compression and study control - observe during use
Electrical	Power	Electrocution	Use battery powered/ certified power supplies
	Electromagnetic compatibility (EMC)	Pacemaker interference	EMC testing*
Thermal	High current	Burns	Limit energy through circuit design

* tests the capability of components/systems to function without emitting intolerable electromagnetic disturbance to anything in the surrounding environment.

9.5 Evaluating garment specification when using a garment as a therapeutic ‘device’

9.5.1 Summarising the role of energy harvesting in Concepts 1.0 and 2.0

Bead Concept 1.0 places the wearer within an active role, contributing to the function of the device by harvesting energy from remaining body movements. Alternatively, Concept 2.0 demonstrates a simplified approach, whereby power is obtained from the tap, harvested from the bead casing. When considering the two concepts more widely, the role of the self is seen on several, differing levels:

1) Providing critical data to inform the delivery of the stimulation protocol[4]
2) Powering the device, in the case of Concept 1.0, promoting an active self
3) The use of piezoelectricity forms a connection between the affected and unaffected areas of the body thereby questioning roles and associations of the contributions that areas of the body have during rehabilitation.

The approach to rehabilitation does not solely focus on the affected areas but utilises mobility in general. This is achieved by the placement of energy harvesting yarns within the unaffected side of the garment. However, this can also be included in the sleeve of the affected limb thereby promoting its active use. FF (2019) and GG (2019) both suggest that it is important to store some of the energy that is harvested. They suggested that, for some people, it can be difficult to move enough and continue to move all the time to continually power the 'bead'. Therefore, rather than having a device that uses energy straight away, it is important to incorporate an energy storage system to enable more people to use it. Without energy storage, the stimulation will only be active during periods of time where the individual is moving significantly enough to harvest enough energy to power the device. Where the piezoelectric component can be utilised in such instances, more extensive research is required to explore yarn-based approaches[4].

Furthermore, in more extreme cases where individuals suffer greater levels of paresis, harvesting energy from body kinesis can be seen to limit use of the device. Powering the device from a combination of this and the resulting taps, demonstrated in Bead Concept 2.0, may be more inclusive of individuals with more severe impairments.

Concept 2.0 also contains additional components within the bead (e.g. microcontroller etc.) therefore reducing the complexity of garment manufacture, but repositions the role of the wearer as a more passive recipient of care. Further tests are required to understand each concept, and whether combining the approaches may be more suitable.

9.5.2 Considering the shape of the Bead, visibility of the component and methods for attaching to the garment

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[4] See Appendix 2.9

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Figure. 9.36 Flange with stitch holes for stitching Bead Concept 3.0 to sleeve

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Figure. 9.37 Cross-section view of full bead render (Author's archive)

Figure. 9.38 Full bead visibility: protruding on the outside of the garment (Author's archive)

[5] 3D printing is gaining popularity in fashion and textiles industries (Iris van Herpen, 2020), presenting opportunities for rethinking how we create materials for the body. In cases where 3D printing can print wider ranges of materials in the future, opportunities for the construction of the 'bead' and other components adding functionalities that currently do not reside in the context of the garment may be made easier to achieve via methods such as 3D printing; Even perhaps constructed simultaneously as the textile itself.

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Figure. 9.39 Top: Half bead render without central ridge form factor
Bottom: Half bead render with central ridge form factor;
(Salisbury, n.d. [b]; Author’s archive)

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Figure. 9.40 Iterations of 3D printed Nylon Bead prototype
Top: Multiple scales of bead/3D printed sample prior to attachement
(a) 30 x 30mm; (b) 15 x 15mm Left: with spine and living hinge, Right: without spine with click-lock bottom;
(c) Left to right: 15 x 15mm, 10 x 10mm, 7.5 x 7.5mm;
Bottom: (d) Stitching the bead to the sleeve; (e) Bead prototype attached to the garment
(Salisbury n.d. [b]; Author's archive)

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Figure. 9.41 Overview of the bead in context to the garment (Salisbury n.d. [b])

9.5.3 Style of garment

A significant challenge in using garments as therapeutic devices lies in the level of diversity in personal style and identity that influences choice and willingness to wear (GG, 2019).

Further, seasonal requirements and potential changes to body temperature following stroke or brain injury mean that several different types of garment may be required at different points of time throughout the year. This is not limited to textile density/thickness, fibrosity/level of pile, but also to colour that can impact level of heat absorbed by the garment and thus transferred to the body.

Having said this, as Table 9.2 states, basic, essential garments may be chosen for their wide acceptance in everyday contexts (PQ, 2020). The versitility of long-sleeved jersey tops, for example, presents the opportunity to pair with different outfit choices, that is, if various colours are available. One significant limitation of the textile component in case study three is in its positioning on the forearm which limits sleeve length, making it more difficult to incorporate into a summer wardrobe. Further technical investigations for placement around the neck or bicep, are required to validate the opportunity to integrate the Bead into shorter sleeved garments.

Finally, depending on the placement of the garment in the patient pathway, use in clinical context may require additional considerations for enabling access to the body for other proceedures to occur, e.g. taking bloods, or blood pressure readings. Rolling up the sleeve where the textile components reside may cause damage over time, and/or interfere with the delivery of treatment. Figure 9.11 demonstrates just one example for designing the sleeve to accomodate this.

9.5.4 Garment Fit and Comfort

Preferences for garment fit were seen to change according to the stage of recovery. Notably, in the earlier stages within a hospital setting, looser fitting clothing was preferred (FF, 2019) due to the impact on levels of comfort and chaffing that tighter garments can present. This changes as individuals seek to wear clothing they would have worn pre-stroke to regain a sense of ‘normality’ (ibid, 2019).

Significant issues arise when incorporating e-textile components that require contact with the body in looser fitting garments. It is firstly important to recognise that, ‘tight fitting’ garments are not the same as ‘close fitting’ garments where the textile can make contact with the body but not have compressive or restrictive qualities.

Furthermore, when considering the level of force that the bead is looking to deliver (up to 15N), user requirements for wanting soft, comfortable garments that have a looser fit can present issues for fulfilling the engineering requirments of the bead. Delivering force effectively typically requires stiffer material qualities, rather than softer materials that are often expected within garments. Such softer materials can dampen the force delivered, however, it should be noted that garments do contain materials of a stiffer quality, typically fastenings, e.g. zips, buttons, or rivets.

Although issues with the requirements of e-textiles to meet functional needs often runs contrary to user expectations of garment qualities, in this case, the bead may be strategically positioned and designed into the cuff of the garment, for example, to make contact with the extensor carpi radialis tendon, whilst being suitably designed as a cuff button.

9.5.5 Considerations for controlling the intervention

Finally, and importantly, the method of enabling the wearer and/or clinician to control the garment can impact willingness to use the therapeutic garment (PQ, 2019). For example, becoming discomforted, annoyed, fatigued or any other negative feeling associated with wearing the intervention, may create the desire to pause or stop the intervention for some time. The intervention may interfere with a social activity or the wearer may simply wish to rest and take a break. Having the option to stop the device without taking off the garment may be important, depending on context of wear.

In case study three, a switch is designed into the collar/ upper chest area of the garment (see Figures 9.14 and 9.25). The position is strategic since the switch is placed in a position that can be accessed easily if wearing a jacket on top, can be incorporated into a logo, and is in a position where the switch is less likely to be pressed or knocked on/off accidentally impacting delivery of treatment and 'dose'.
It is suggested that, due to limited dexterity, the switch is integrated onto the most affected side of the body so that the less affecteed arm can be used to press it (KK, 2019). The type of textile switch requires exploring further since the type of the switch will require a different gesture and level of energy to push, swipe or flick. The size and level of comfort all impacts user experience and continued use.

It should also be acknowledged that the use of switch in pausing the therapy may likely impact the clinical effectiveness of the therapy. This needs to be considered when designing the intervention. Investigations for optimum 'dose' and intensity of delivery are necessary. This does not necessarily mean that individuals will adhere to instructions of use if they understand the benefits of receiving a full dose compared to partial dose, but it provides a level of information that can enable the wearer to make an informed decision when wearing the garment.

Overall, Chapter nine has sought to demonstrate a range of key opportunities and limitations for using the garment as a therapeutic intervention and, via case study three, suitably incorporating components into the garment.
It may be necessary to work with existing components to test the intervention at first, whilst maintaining thoughts for manipulating or re-making components to suit the textile 'environment'. The most significant issue with using voice coils in Bead Concept 3.0 is the size of component required to produce the stimulation protocol. As seen in Figure 9.32, this 'bulk' (~30mm profile) may pose issues during use of the wearer catching or knocking the component, interfering with its positioning on the body and the delivery of the intervention.
It is considered that findings from this case study, although somewhat specific to the study, can inform the use of the garment as a therapeutic intervention and the designing of e-textile components. The conclusion will look to summarise key findings in order to complete the thesis.

CONCLUSION

10.1 Thesis conclusion: Summary

Wearable methods of administering healthcare have seen a rise in interest (Attard and Rithalia, 2010; Coghlan et al., 2019; Richards et al., 2020; Zhao et al., 2020), blurring the boundaries between [health]care environments as we historically know it, and the everyday (Joyce, 2019). Wearable methods provide models of healthcare that can involve active participation, decision making and self-monitoring within the act of care. Yet this also comes with significant challenges in how, where, and why functionalities of care can and should be integrated into the garment.

The garment proposed in this thesis is one such example presenting specific opportunities for reconsidering how, when and for how long it is possible to intervene with body functions. This research examines the positioning and characterisation of the garment as a therapeutic intervention, as a method for enhancing long term rehabilitation within the community. It does so through four Case Studies through the lens of stroke rehabilitation. Table 10.1 presents an overview of how these Case Studies sit within the thesis and inform wider learnings around the development and positioning of garments as therapeutic 'tools'. There exists an iterative nature of how each case study builds upon the latter. Learning through the process of making, is crucial since the notion to wear brings with it particular qualities that change the way we behave and requires testing, fitting and 'trying on' with stakeholders. The research questions investigated and uncovered the following findings:

Research question (i): What are the most significant challenges existing in current and near future post-stroke upper limb recovery?
Challenges include delivering functional recovery treatment to those with moderate to severe upper limb impairments who may be unable to engage with some interventions (ULP:d, 2018, see Chapter one). Further, methods of rehabilitation may not be suited to behavioural/ lifestyle needs (FF, 2019, see Chapter three) and it can be difficult to meet the daily recommended dose.

Early rehabilitation is recommended yet early intense rehabilitation, specifically concerning electrical stimulation, is met with objection for fear of exacerbating lesion volume (Humm et al., 1999; Cortes and Krakauer, 2018). It can also be difficult for patients to access rehabilitation rooms with training tools, especially for those with severe impairments (CO, 2019). There are also limited datasets and understanding of 'life after stroke' (Drummond, 2020) or activities performed outside of therapy sessions (Stockley et al., 2019) beyond the first six to twelve months post-stroke, within which the majority of data exists. Additionally, there exists challenges in determining *"how well research evidence is being translated into routine practice and informs therapy provision"* (ibid) as well as identifying and comparing existing and newly proposed methods.

The above clearly demonstrates the need for innovative thinking for interventions within stroke rehabilitation that enable patient agency, independence and improved recovery outcomes beyond the confines of the training room (see Chapter one).

Research question (ii): Why is there a need to intervene?
Treating the differences in ability that may arise from stroke that are seen to be diverging from the “norm” can be challenging because of the entrenchment of treatment in underlying and long term social ideologies relating to the ‘norm’ (Chapter two). It therefore becomes important for researchers to discern whether intervening is of holistic benefit or, alternatively, contributing to a lack of acceptance of disability in society. Each intervention will need to be explored as per the specific healthcare need that is being attended to and the social and ideological context in which it sits. In the case of supporting functional recovery of upper limb paresis in this thesis, it was important to not only view this from the perspective of the medical model but from the social model to provide a contextual understanding of individuals recovering from stroke (Bose, 2017).

Individuals can, do and should be able to live with a deficit such as an absence of a limb, lack of ability etc. which is a part of who they are and their life experiences.
However, when evaluating wider ongoing consequences resulting from non-use as a result of stroke, issues such as stiffness, swelling and pain can arise which in themselves can hinder lifestyle choices, self-perception, self-expression, and identity.

Preventing a decline in health however, is considered a good reason to intervene.
However, this should also come down to individual ‘patient’ choice which requires greater awareness and understanding of living with a disability. It is clear, however, from findings presented in Chapters two and three, that such decision making can be influenced by social ideologies and the want to fit into and be a part of the ‘norm’.

The researcher has endeavoured to answer the question “why intervene” and in doing so has uncovered the complexity of impact of social ideologies on choices in healthcare. Since there exists a gap in offering support to individuals with more severe upper limb impairments, as well as enabling individuals with less severe deficits to maintain rehabilitation in a manner that was suited to their lifestyle and behavioural needs, the thesis positions the research in this gap of inequality.

Research question (iii): What are the opportunities for using a textile/ garment-based intervention?
In addressing this research question a shift occurred in the positioning and focus of use of the garment. From using the garment as a design probe and research tool for unpacking conversations around care, sense of self and lifestyle choices, building on Chapter two, the garment became identified as a potentially powerful tool for intervening (see Chapter three) and addressing some of the gaps identified in Chapter one. In particular, the research identifies and draws upon the regular, ‘intimate’ and ‘mobile’ correspondence the garment holds with the body (Spinoza, [1677] 1993; Ruggerone, 2017) as an opportunity to re-consider the delivery and positioning of rehabilitation interventions relative to highly complex associations with being and becoming (Heidegger, 1926); including ‘identity’ and behavioural traits post-stroke. Key qualities of the garment

including the close, intimate contact that the garment has with the wearer (Van Langenhove et al., 2007), duration of contact the garment can have during the day and the ability to span public and private contexts of wear, provide opportunities for intervening. All of these points can help improve and increase levels of engagement, the 'dose' and delivery of healthcare alongside ADLs.

Beyond this, where access to healthcare lags the improvement in nutrition in developing low-middle income countries and the costs of traditional stroke therapy are outside of the means of many individuals, mobile-based methods may be very important for these large populations.

Furthermore, the 'familiar' notion of the garment is considered useful since it is both universally understood in how to use it, as well as having an identity that can be ingrained within the everyday (depending on style and garment composition of course). The ability to manipulate qualities of style, fit and comfort has the potential to improve overall compliance of use with therapeutic interventions as well as the ease of set-up (dressing) and use (wearing). But beyond this, there exists both opportunities and challenges in the way the garment is designed which can either exacerbate or reduce the negative impact of underlying social ideologies relating to the pursuit of the 'norm'. As such Chapter three identifies that such medical device components can be either concealed, highlighted or designed and integrated in such a way that seeks to support a long-term repositioning of them as 'everyday' objects. Such arguments are built upon in addressing research question iv.

Research question (iv): What are the barriers for utilising a garment in the space of healthcare, specifically stroke rehabilitation?
Building on research question iii, key barriers are linked to the individual nature of the garment for expressing identity as well as the difficulty in components meeting the qualities of textile and garment behaviours that are a key part of supporting adoption of a wearable. Components often have to deal with expected needs for being flexible, breathable and comfortable (Salisbury, n.d. [a]). Further, components are required to be small and lightweight enough so to be easily 'carried around' or worn throughout the day without being knocked, damaged, or causing discomfort during wear. But beyond this, issues with trust and acceptance of wearables still persist. In some instances, when components are carefully integrated into the garment in a way that is 'invisible', a level of scepticism and mistrust can be generated: *"can a textile really do that?!"* (CE, 2019).

Further, the garment can attend to issues of identity but not without significant challenges in doing so. As "social signifiers" (Bourdieu, 1984; Wilson, 1985; Skeggs, 1997; Crane 2000), garments can hold stigma, for those who adhere to 'social codes' (Entwistle, 2000), they reduce the risk of ridicule, stigma and exclusion. Through the construction of the 'norm' (Chapter two) social codes determine which body image and 'sense of self' is appropriate in which context, and which are excluded. The lack of choice of wearing garments one used to pre-stroke, can impact behaviour and mood: *"I felt really uncomfortable [going outside] because I can't wear that top, put my earrings in, can't put my makeup on"* (HH, 2019).
Findings from understanding perspectives of care demonstrated that the garment is not simply a vehicle in which medical components are integrated, but it in itself (the garment) holds an agency and capability to influence compliance towards treatment, and quality

of life, impact how others treat the stroke survivor in the manner in which healthcare and health conditions are visible to others. Notably, garment style can influence mindsets towards rehabilitation. For example, in chapters three and nine participants suggested that ‘sports’ or ‘gym wear’ made them feel more ‘active’ than a ‘comfy jumper’ would: *“When you put on sportswear or gym clothes you feel like you’re getting ready to train. It makes you feel more active, you act a bit different to just wearing a regular top”* (DF, 2019). *“Yeah maybe you need a couple of different types of garments like one for training, one for when you’re just relaxing like a comfy jumper so you can just rest”* (LM, 2019).

However, gym wear was only popular with 39% of all participants, limited by the suitability to particular lifestyles. For everyday casual use alternative garments are considered: *“You want to look cool and like you care about what you look like. You don’t want something that is drab. But actually, it can be useful to have a basic like t-shirt so you can just wear it with anything, under your shirt, a jumper, or by itself”* (TT, 2019). *“Also, if you have to move a lot to power it [the bead] then you would need to feel active”* (DF, 2019).

It is therefore clear that when considering what style, fit, colour and texture of the garment, user perception, their relationship with textiles and garments in general, are driven by social codes (Entwistle, 2000) and are areas for researchers to consider.

However, beyond this, further challenges arise when integrating medical devices or components into the garment which add a new layer of complexity to self-perception and identity for the user, further skewing identity (ST, 2019). Participant responses (see Chapters three, seven and nine) have revealed that a detachment from ‘treatment’ or concealing an ‘aid’ or device is preferred in order for individuals to avoid attracting further stigma or conversations of their ‘otherness’. *“When people see you wearing the aid on a regular basis, it becomes part of you, how they see you”* (AA, 2019).

Participants recall becoming known or recognisable by their health status which can be made more visible and distinguishable by a wearable device or aid. There is often a failing to acknowledge the *“person within the body”* (WW, 2018) instead focusing on the disability, dislocating the person from their ‘disease’. Wearing something that is different is seen to exacerbate an existing difference, whereas wearing something that is also worn by the wider population is seen to help reduce difference between ‘abled’ and ‘disabled’ communities, if such a difference can be made.

Indeed an open display of such components can draw attention, acting as stark reminders of life events individuals wish to forget. It could be argued that, in concealing the components, this contributes to concealing disability or perceived ‘difference’ that only complies to societal figures of norms (see Chapters three and seven). The wearable therefore brings the lack of ability into a social domain which inevitably brings new types of interaction, conversation and relating to and from others, as evidenced in Chapters three and nine.

This research has clearly reveals the dilemma of developing interventions that are effective and shorten recovery time for the patient whilst also addressing the social relationships and social context within which the user lives. It has identified the manner in which fashion can promote the diversification of sense of self expression within wider fields such as healthcare, helping to improve compliance of use. However, although this may be the case, fashion is and can be heavily driven by influencers, promoting particular body images and styles that are considered 'on trend' or of the current 'norm'. Levels of exclusion still remain and require addressing when developing a wearable intervention. It is considered that there is no 'one-size-fits-all' model, since uniformity is often associated with hospital gowns, for example and other types of uniform, differing from the everyday choices of garments to wear. Having said this, there are commonalities between essential garments such as the humble t-shirt which can transgress age, gender and ability, albeit with diversity of style (colour, neckline, fit etc.) still remaining a personal choice and differentiating factor between different types of t-shirts. This is a major consideration beyond the remit of this inquiry, and will be addressed in the ensuring fellowship.

Research question (v): What mechanisms contribute to upper limb function?
Several neural pathways are known to contribute to the control and function of the hand and upper limb. These include: the corticospinal tract (CST), contributing to finer motor control in the most part, and grip strength; rubrospinal tract and reticulospinal tract (RST) which act in parallel to the CST. Such pathways can be manipulated to improve upper limb recovery. In this thesis, this is achieved by delivering a short, sharp tap and an acoustic cue to activate or suppress muscle activity.
The following research question addresses what is considered to be an essential piece of information that is needed in order to effectively intervene. The importance of not only understanding the gap or space in which the research is positioned (Chapters one to three), but the need to understand the physiological implications of intervening was considered crucial to the development of concepts in Case Study four (Chapters five to nine). This inquiry could not have progressed without incorporating physiological aspects of stroke in order to identify functional needs for intervening including the dialogue between such functional needs and the garment itself, e.g. material, texture, weight, etc. This is further addressed in the research question vi below.

Research question (vi): How might a textile (component) manipulate the underlying neural pathways which dominate control of the hand and upper limb?

[The following text that appeared in the thesis was redacted due to its commercially sensitive nature.
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Research question (vii): How is the role of the wearer/ recipient of care positioned in accordance with the delivery of care and how do the material choices impact this?
Where the role of the wearer can be, and often is a passive one, there also exists opportunities for the wearer to actively contribute to the functionality of the device. Within this thesis this change in roles is explored through the use of piezoelectric materials in experiments. The use of body kinesis for powering the device specifically reconsiders the

role of the self in receiving care from a device. The advantage in stroke rehabilitation is that this promote
who can remain mobile enough to develop enough power to activate the device. Further, the level of ene
millivolts. In reference to calculations made for the energy required to power 'Bead Concept 3.0' [redacted]
include the use of rechargeable batteries, or even a hybrid system incorporating batteries and energy h
and aftercare, specifically washing. Further research is required to evaluate this further.

The opportunities and challenges for developing the garment as a therapeutic intervention are explored
the research questions (Section 10.1), as well as summarising the contribution to knowledge (Section 10

Aims:
Understanding the stroke landscape and questioning the need to intervene

Attending to research questions:
i) and ii)

Aims:
Exploring
of the gar
interventio

Attending
questions

Anthropological Studies
including:

- Clinical observations
- Outpatient group meetings
- Stroke seminars
- Charity community support groups

Literature Review

Participatory studies

- Exploring stakeholder perspectives
- Using the garment as a design probe

Ca
Positioning
intervention
stroke reha

Ca
Rethinking me
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info

Ca
Re-position
between
Dewei

Ongoing anthropological studies - *providing a 'touch point' wi*

Table 10.1 An overview of the
one to four in perspective t

es the individual to remain as mobile as possible. The challenge here is that this may limit use to those ergy that can be generated from piezoelectric materials in the garment is limited in the most part to [redacted], this is not enough to fulfill the power requirements. Alternative options can arvesting systems. However, the use of batteries presents challenges in the behaviour of recharging

in each chapter. This conclusion chapter highlights the main opportunities and challenges relative to 0.2) and indications of future work (Section 10.3).

the potential role
ment as an
onal tool

g to research
s: *iii) and iv)*

Aims:
Unpacking underlying mechanisms influencing upper limb recovery

Attending to research question: *v)*

Aims:
Exploring, testing and developing materials for intervening using the garment and 'Bead'

Attending to research questions: *vi) and vii)*

se Study 1
the garment as an
integrating existing
abilitation methods

se Study 2
ethods integrated into
nt to promote and
rm mobility

se Study 3
ing the intervention
times of training:
ghting the limb

Literature Review

Consultations and interviews with:

- Professor of movement neuroscience
- Senior stroke research fellow
- Physiotherapists

Case Study 4

Intervening in order to contribute to functional recovery by modifying reticulospinal and corticospinal input to forearm flexor and extensor muscles

th everyday contexts experienced by stakeholders

positioning of Case Studies
the research structure

10.2 Contribution to knowledge

The contribution to knowledge of this research sits within four main areas:

1. Identifying the opportunities and challenges for using garments as therapeutic interventions within stroke (with some findings applicable to further areas in healthcare);

2. Providing and demonstrating a transdisciplinary framework for the development of garment-based therapeutic interventions;

3. Supporting greater equality in stroke research by contributing primary evidence to the experience of stroke survivorship beyond the limitations[1] currently faced with data in the field and beyond offerings from the medical model, providing research from a bio-social model perspective;

4. Developing a patent-pending textile concept (The Bead) with theoretical potential for contributing to upper limb functional recovery post-stroke (Patent number: 2013574.5; Filing date: 28/08/20; PCT date: 17/08/21).

The transdisciplinary framework brings together areas of stroke, material science, electronic engineering, fashion and textiles with inclusive design in a manner that has not been done before within a research project. By drawing upon these areas critical factors including comfort, identity, use of wearable therapeutic interventions as well as the size, weight, compatible methods of integration to textiles are considered alongside their functionality. Such factors hold critical positions for influencing uptake and compliance of use of garments.

The framework used to conduct the research can be applied to other research projects exploring the development and uptake of wearable medical devices. Further, the framework contributes to helping to shape Inclusive Fashion[2] (Otto von Busch, 2018) beyond approaches designing adaptive wear and into functional therapeutic device components. In doing so it helps question current approaches to designing for disability and healthcare.

The research therefore contributes to number nine of the United Nations sustainable design goals (UN's SDGs) in promoting and establishing new areas of inclusive design innovation impacting industry development within the area of fashion, textiles and wearable technology (Salisbury, Ozden-Yenigun and McGinley, n.d.).

[1] Evidence and an understanding of the experience for stroke is currently limited. Data from mild to moderately impaired communities dominates knowledge and data beyond 12 months is severely limited (Drummond, 2020).

[2] Defined in the context of this thesis as: attending to a diversity of identity, perspective, needs and desires. In short we can categorise 'Inclusive Fashion' into the following areas:

a) In terms of wearing fashion and expressing oneself:

i) Enabling individuals of diverse sizes and shapes to be included in particular fashion that were once inaccessible;

ii) Removing barriers that prevent individuals from accessing fashion as a result of being categorised as disabled or due to age;

iii) Enabling individuals to express themselves without discrimination of their gender, sexuality, ability, race, ethnicity, size and shape;

b) In terms of representation and participation Inclusive Fashion aims to fairly represent diversity and inclusion of ethnic minorities, age and ability within all areas of fashion business and culture.

10.3 Future research

This PhD has laid the groundwork for which further developments of the 'bead' component may improve lives. Further work (Figure 10.2) is required to conduct wearer tests to understand how the garment type impacts use, refine the specifications for multiple seasons beyond autumn winter as the jumper in this thesis presents, material characterisation, development, and electrophysiology testing to prove the concept, refining of stimulation parameters, leading to product optimisation. This will all be conducted in a UKRI Future Leaders Fellowship awarded to continue the work established in Case Study four.

Key future research questions include:

[redacted]

[The following text that appeared in the thesis was redacted due to its commercially sensitive nature.
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Beyond this, the thesis opens up further questions within the theoretical enquiry, namely in regards to:

a) What are the dangers of pursuing 'Inclusive Fashion' for the impact on social structures and hierarchies?

b) Will there be a shift in skill set required for 'Inclusive Fashion' to be fully realised?

c) What might be the impact of this on educational and vocational systems; and further, the correspondence between first and third world sectors?

d) In creating diversity of garments as 'medical devices', attending to cultural, gender and wider social needs, what impact will this have on the future of medicine and the acceptance of garments as tools for recovery?

In conclusion, the researcher recognises and acknowledges the need for the development of the garment as a therapeutic device in the holistic context of the patient as one entrenched in society with a daily lived experience. Further the multidisciplinary scientific input needed to deliver such a garment that meets a healthcare need and the social, psychological components necessary for successful deployment and commercialisation of the garment.

Given that as this inquiry progressed, new layers of complexity emerged as stated in Section 10.1, the researcher is deeply thankful for the opportunity to continue the inquiry, addressing the above factors identified through a four year fellowship subject to a three year extension.

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Figure. 10.2 Summary of next steps

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GLOSSARY OF KEY TERMS

Term	Definition
Atrial fibrillation	*A common type of irregular heart rhythm that increases risk of a stroke (UCL Partners, 2020)*
Availing	*To 'benefit' (Heidegger, 1947)*
Behavioural learning/ restitution	*"A return towards more normal patterns of motor control with the impaired effector (a body part such as a hand or foot that interacts with an object or the environment) and reflects the process toward 'true recovery'" (Levin et al., 2009; Zeiler and Krakauer, 2013 in Bernhardt et al., 2017)*
Contracture	*Shortening of muscles*
Dasein	*From the German meaning "being there" or "presence"; a fundamental concept of Heidegger's existentialism (Heidegger, 1926: 155)*
Dielectric	*An electrical insulator that can be polarized by an applied electric field and sustain a static electric field within it.*
Disability	*"The loss or limitation of opportunities to take part in the normal life of the community on an equal level with others due to physical and social barriers" (DPI, 1982)*
Dtex	*(Decitex) is a unit of measurement that relates to the weight or density of the yarn by indicating the linear mass of yarn in decigrams, per 10,000 metres*
Energy density	*The amount of energy stored in a given system, substance, or region of space per unit volume*
Eugenics	*Developed largely by Sir Francis Galton as a method of improving the human race, eugenics was increasingly discredited as unscientific and racially biased during the 20th century, especially after the adoption of its doctrines by the Nazis in order to justify their treatment of Jews, disabled people, and other minority groups*
Hyperreflexia	*"Overactivity of physiological reflexes" (Merriam-Webster, 2020)*
Impairment	*"The functional limitation within the individual caused by physical, mental or sensory impairment" (DPI, 1982)*

Infarct	*Tissue death*
Interfacial bonding	*Refers to the quality of intermolecular forces between two materials*
Ischemia	*"Deficient supply of blood to a body part (such as the heart or brain) that is due to obstruction of the inflow of arterial blood" (Merriam-Webster, 2020)*
Material heterogeneity	*Refers to the complexity of material composition and the relationship of the material contents to one another*
Motor control	*"Ability to regulate or direct the mechanisms essential for movement" (Medical Dictionary for the Health Professions and Nursing, 2012)*
Muscle spindle Ia afferents	*"The primary afferent fibre (Ia) is 12-20µm in diameter. They conduct impulses at up to 120m/sec, and their central processes within the spinal cord participates in the monosynaptic stretch (myotatic) reflex that regulates muscle tone" (Fitz-Ritson, 1982)*
Negative and positive symptoms	*Negative symptoms pertain to the loss of voluntary movement. Contrary to this, the intrusion of positive symptoms denote the emergence of phenomena such as spasticity and synergies which are not observed in rodents, for example, but present in humans. Where rodent models of study can be useful and contribute to knowledge, they have their limitations (Krakauer, 2018).*
Neuromodulation	*"a field of science, medicine and bioengineering that encompasses implantable and non-implantable technologies, electrical or chemical, [including NIBS and DBS] that impact upon neural interfaces to improve life" (International Neuromodulation Society, 2009).*
Neuroplastic	*"The ability of the nervous system to change its activity in response to intrinsic or extrinsic stimuli by reorganizing its structure, functions, or connections. A fundamental property of neurons is their ability to modify the strength and efficacy of synaptic transmission through a diverse number of activity-dependent mechanisms, typically referred to as synaptic plasticity" (Mateos-Aparicio and Rodríguez-Moreno, 2019)*
Paresis	*Weakening of muscles*
Plegic	*From the Greek plege meaning a blow or stroke*
Postischemic sensitive period	*"When the effects of experience are particularly strong on a limited period in development" (Knudsen 2004: 1412)*
Quality of life	*Refers to the level of comfort, enjoyment, and ability to pursue daily activities*
Relative permittivity	*"The ability to polarize a material subjected to an electrical field" (Dorey, 2012)*
Semantic	*An interest in the construction of meaning, its significance and implications*
Shoulder subluxation	*Temporary and partial dislocation*
Solicitude	*Care or concern for someone or something*
Spasticity	*"An abnormal increase in muscle tone or stiffness of muscle, which might interfere with movement, speech, or be associated with discomfort or pain" (NIH, 2020)*

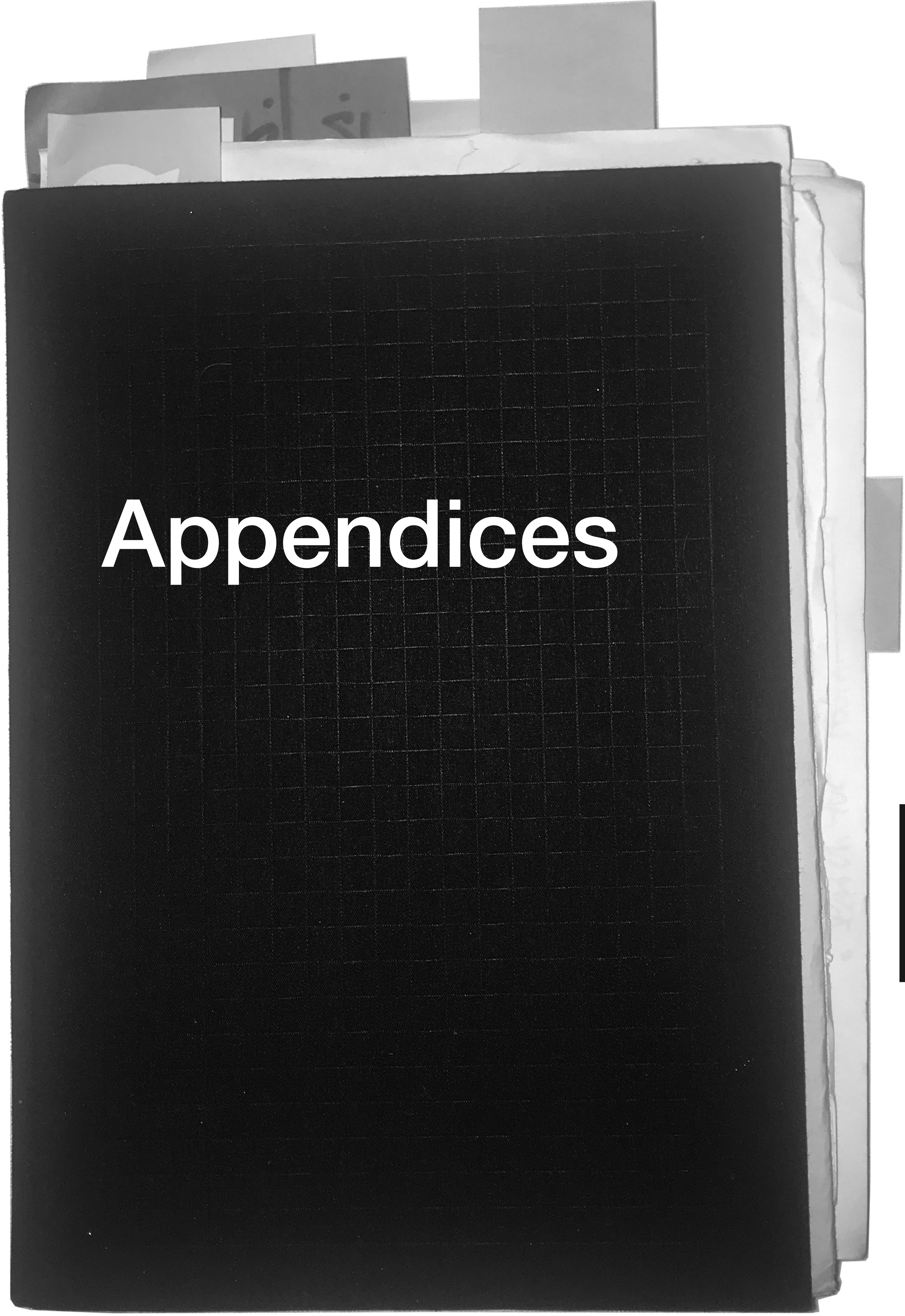
Spontaneous biological recovery	*"Defined as the amount of neurological improvement of body functions such as synergy, attention, and strength that is determined by the passage of time alone. Most neurological improvement is found within the first days and weeks after stroke" (Kwakkel et al., 2014)*
Subluxation	*An incomplete or partial dislocation of a joint*
Synaptic plasticity	*"Synaptic plasticity represents one of the most fundamental and important functions of the brain, which is the ability of the neural activity generated by an experience to modify neural circuit function and thereby modify subsequent thoughts, feelings, and behavior" (Godos et al., 2019)*
Task-oriented approach	*A strategy based on motor learning principles which shifted from facilitation-based approaches in the 1980s (i.e. the encouragement of 'normal-looking' movement patterns through assistive guidance) to motor learning (methods largely based on compensatory techniques: teaching individuals how to 'cope' and survive but not how to regain function). Indeed, motor learning methods are "fine for learning compensation but don't equate motor learning to recovery" (Krakauer, 2018)*
Toile	*An early version of a finished garment made up in cheap material so that the design can be tested and perfected. (Oxford English Dictionary, 2020)*
Tone	*"The continuous and passive-partial contraction of the muscle or the muscle's resistance to passive stretch during the resting state" (DeMott and Flinn, 2020)*
Transdisciplinary	*"Co-creating new knowledge beyond disciplinary perspective to transcend disciplines", rather than cross-disciplinary "one discipline considered from the perspective of another" (Coulter, 2018)*

KEY ACRONYMS & ABBREVIATIONS

Acronym/ abbreviation	Long hand
ACU	Acute care unit
ADLs	Activities of daily living
DBS	Deep brain stimulation
ESD	Early supported discharge
FES	Functional electrical stimulation
HACU	Hyper acute care unit
MSAs	Muscle spindle afferents
NDT	Neurodevelopmental treatment
NIBS	Non-invasive brain stimulation
OT	Occupational therapist
PENG	Piezoelectric nanogenerator
PT	Physiotherapist
PTFE	Polytetrafluoroethylene
PVB	Polyvinyl butyral
PVDF	Polyvinylidene fluoride
RCP	Royal College of Physicians

SSNAP	Sentinel stroke national audit programme
TENG	Triboelectric nanogenerator
TMS	Transcranial magnetic stimulation
UPIAS	Union of the physically impaired against segregation

Appendices



APPENDIX

1.0

Key fashion theories exploring the ‘garment’, ‘body’ and ‘mind’

Cartesian models of mind: body dualism is a position taken by significant literature (Simmel [1900], 1989; Davis, 1992; Finkelstein, 1996, 1998, 2007; Entwistle, 2000). The correspondence between the garment and self is considered on rational and cognitive basis; on an intellectual level and devoid of sensory, tacit and non-rational considerations. It is the mind that is seen to govern the choice of garments separating the act of dressing from the body (Lefebvre, 1991) by suggesting that the mind, as an immaterial force, holds control and constructs an idea or image of sense of self which then becomes applied to the body. Fashion, in this sense, is seen as a way of constructing and representing complex social egos (Simmel [1900], 1989; Finkelstein, 1996, 1998, 2007) and rendering practices as “bound events” (Ruggerone, 2017). The rise of ‘affect studies’ (Spinoza, [1677], 1993; Nietzsche, [1901], 1968; Deleuze, 1988; Ruggerone, 2017) and ‘relationalism’ (Ingold, 2010, 2018; Barad, 2014) has provided alternative perspectives to this.

Affect studies (in fashion theory) focuses on “the investigation of the body-clothes assemblage” (Ruggerone, 2017) within the domain of fashion and the social sciences; and Deleuze’s notion of the “body as a composition of forces” (2007; Buchanan, 1997) in the process of becoming. This particular line of thought is seen to originate from feminist theory and cultural geography, which can be seen to influence and provide new perspectives in disability studies (Garland-Thomson, 2005). Practices and the act of dressing are perceived as “fluxes or becomings” (Ruggerone, 2017), interrelated events and inseparable and continuous from other happenings. These ‘events’ equally continue beyond the act of dressing, into the act of wearing, whereby changing correspondences between the self and ‘others’ and of the garment and ‘others’ are increasingly complex. The notion of affect, defined as the “capacity that a body has to form specific relations” (Buchanan, 1997: 80) with other human or non-human bodies functions on a ‘pre-cognitive’ level. The set of relational dispositions cannot be controlled by the mind, so the potential of the body to form relations with ‘others’ is not controlled by the mind but is actually uncontrollable altogether (Ruggerone, 2017).

Relationalism, on the other hand, rejects the distinction between human and non-human ‘things’, which, in ‘affect studies’ and Cartesian dualism can be seen to take a humanism standpoint; e.g., the closeness in correspondence between garment and self that Winnicott (1971) describes as “both me and not me” (Also; Woodward, 2007). This places a focus on ‘embodied encounters’ which suggests a hierarchy of order whereby the human self is placed above other material ‘things’ and ‘beings’, albeit not in control in ‘affect studies’.

‘Relationalism’ rejects further binary notions of ‘continuity’ and ‘discontinuity’, ‘a part of’ and ‘separate from’ in favour of a spectrum of temporalities that are not specific to human or non-human ‘beings’: “redefined through discussions of diffractive apparatus, more-than-human performativity, and the polymorphous perversity of the matter-meaning mixture” (De Frietas, 2017). A part of a world with multiplicity of correspondences “one that is never finally formed but ever in formation” (Ingold, 2018); where in the method or process of correspondence occurs between materials and forces (Deleuze and Guattari, 2004: 377) rather than between “matter and form”, contrary to the hylomorphic model (Ingold, 2010: 91).

Becoming isn’t linear or replicable but rather exists within a complexity of other becomings that neither has a ‘start’ nor a ‘finish’: “We are inter-subjects. Our actions and thoughts aren’t reducible to us alone. They are moves in a game which has many players, responses to a call to action which is expressed in every gesture of the other” (Crossley, 1996).

APPENDIX 2.0

Supplementary material from sampling and experimentation

Appendix 2.1 A summary of yarns used

Table A2.11: A summary of yarns used in experiments for Concepts I, II and III

Yarn name *(as stated in the text)*	Colour	Composition	Count *(Dtex)*	Metric count *(Nm)*
Pemotex	White	100% polyester (PE)	510	-
'Wool'	Blue	100% acrylic	-	2/30
Nylon monofilament	Transparent	Unknown polyamide content (PA)	150	-
Polypropylene	Blue; black	Polypropylene (PP)	40	-
Elastane	White	Undisclosed amounts of Polyester and Polyurethane	-	1/65
Inox (100%)	Grey	Stainless steel	550	-
Inox (100%)	Grey	Stainless steel	110	-
Copper/ Silver	Silver	50% Cu/ 50% Ag	320	-

Appendix 2.2

A Practice Diary:
Supplementary sample photos

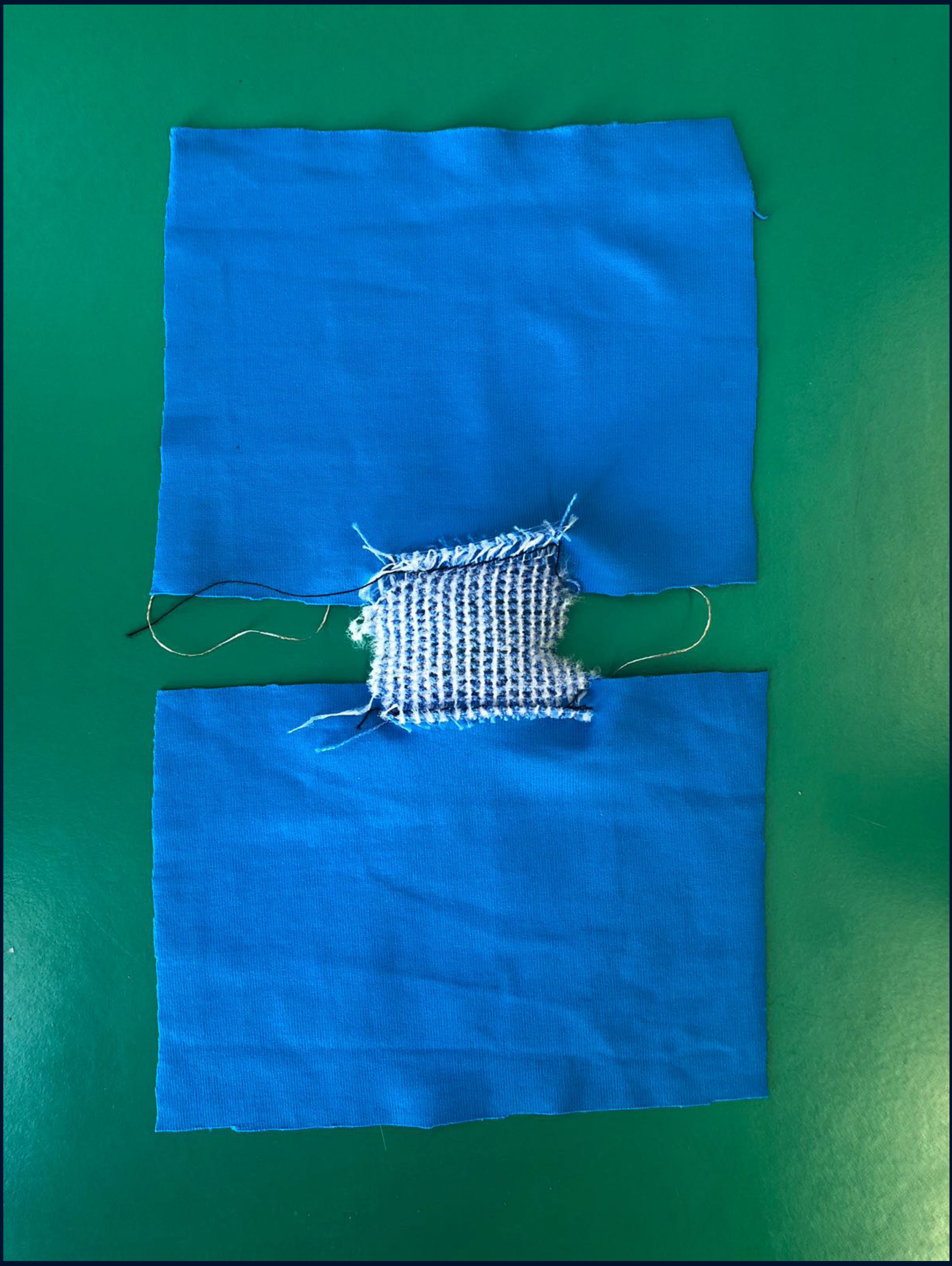


Figure A2.21 Lino weave post shrink.
(Author's archive)


Figure A2.22 Garment - top: Changing the sleeve's circumference to restrict or free the limb (Author's archive)

Figure A2.23 Garment demonstration sleeve fit; Left: Before; Right: After (Author’s archive)

Figure A2.24 Creating the textile: Twill
(Author's archive)

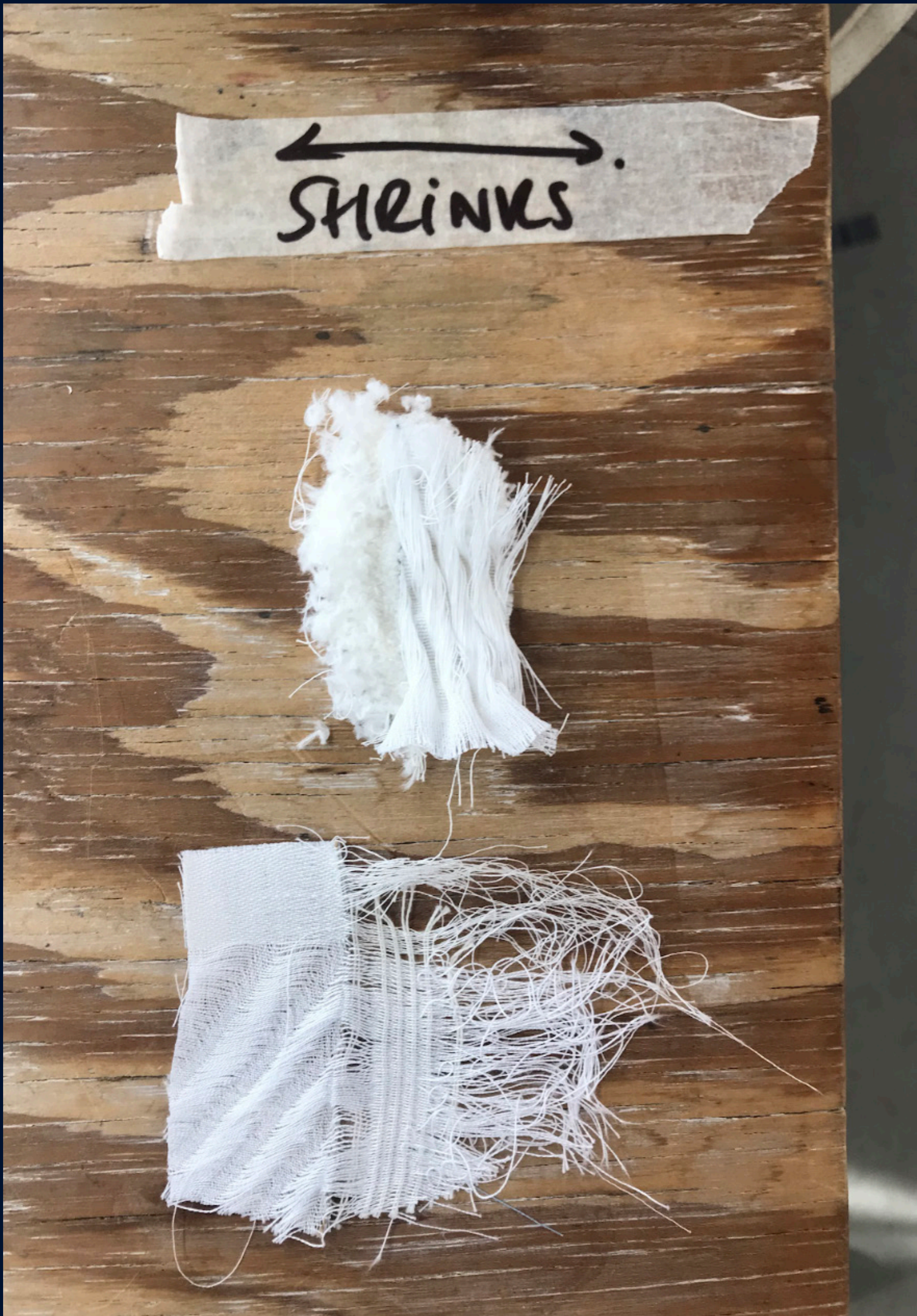


Figure A2.25 On the cutting room table: Indicating the direction of shrink along the weft (Author’s archive)

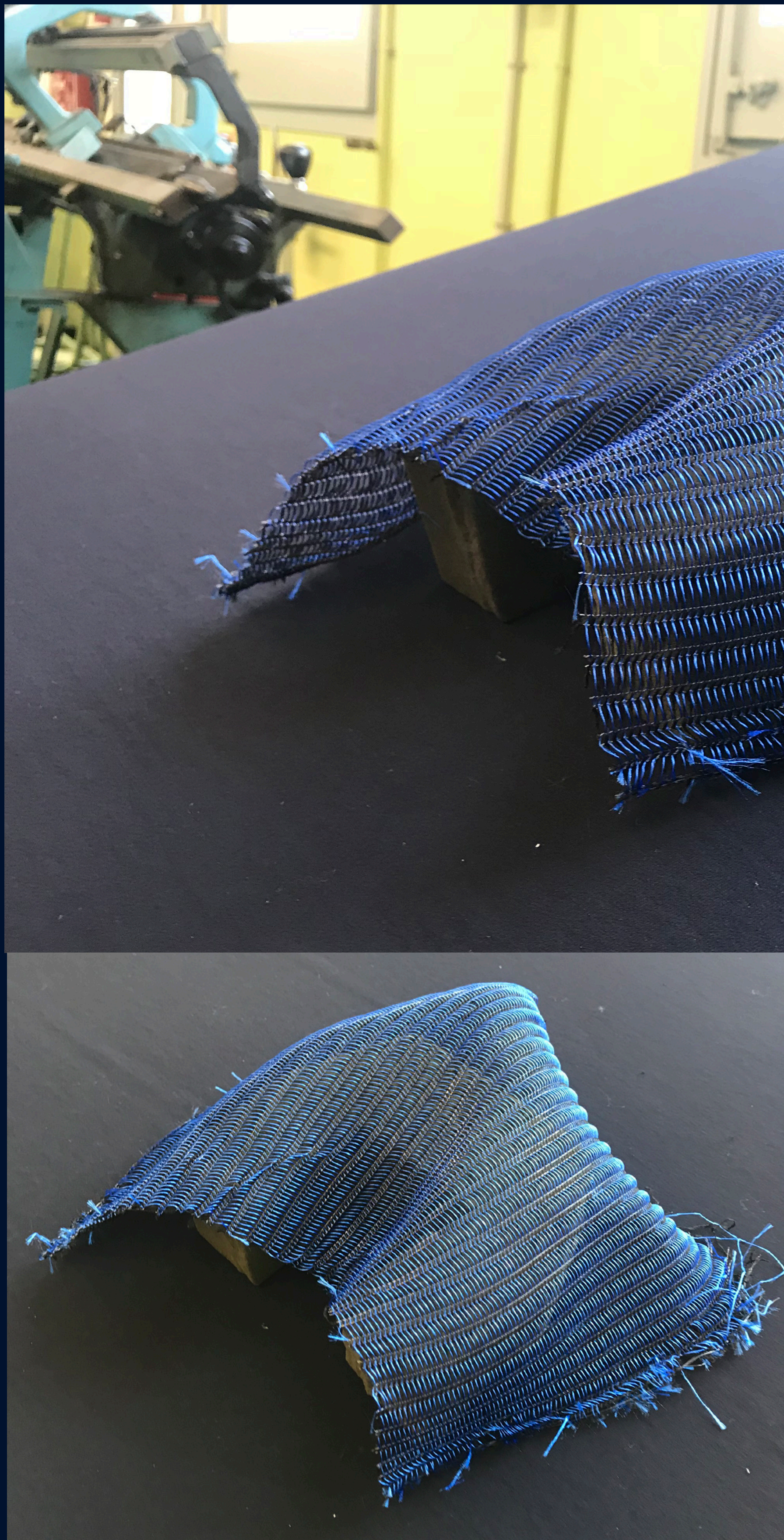
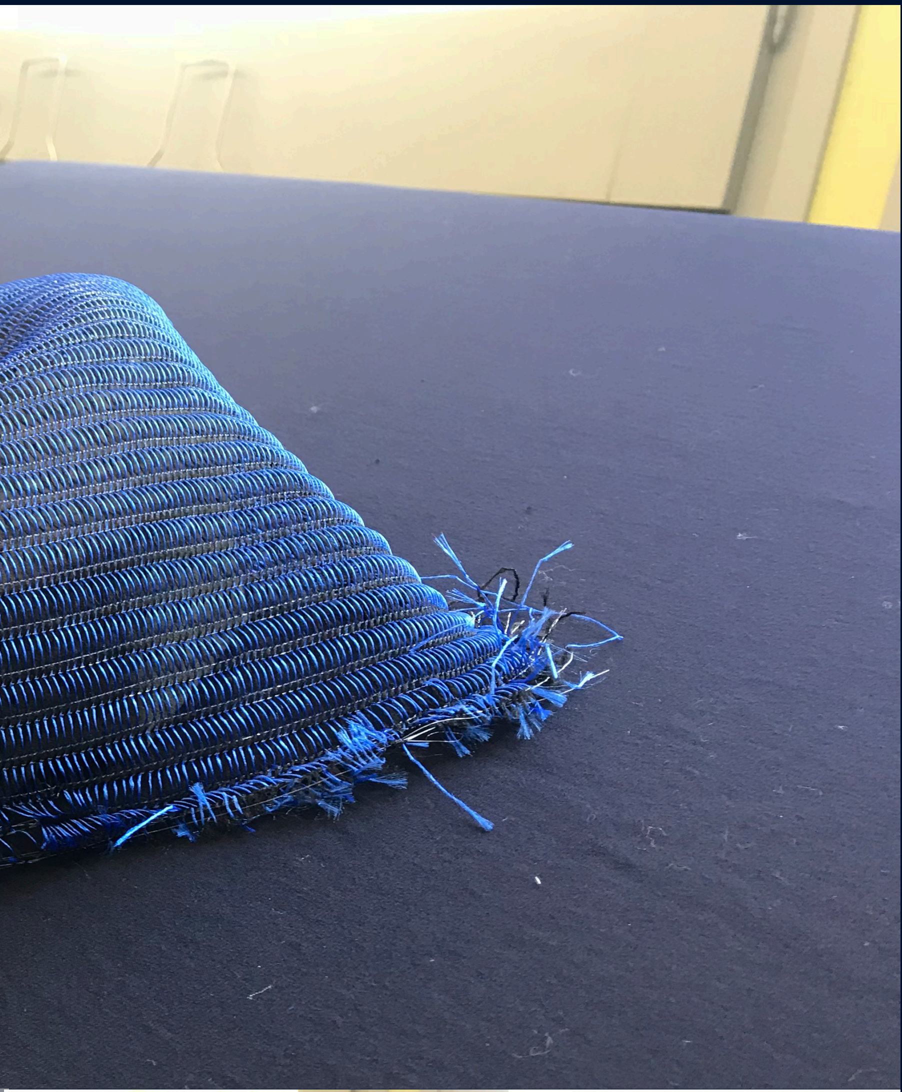
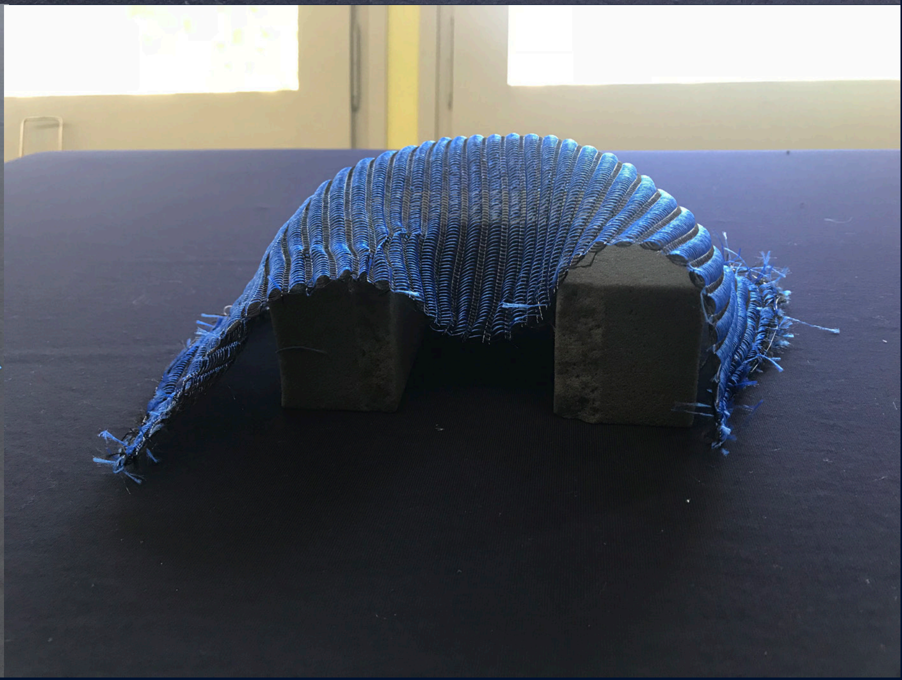


Figure A2.26 Placement perspectives of the sample on the heat bed (Author's archive)





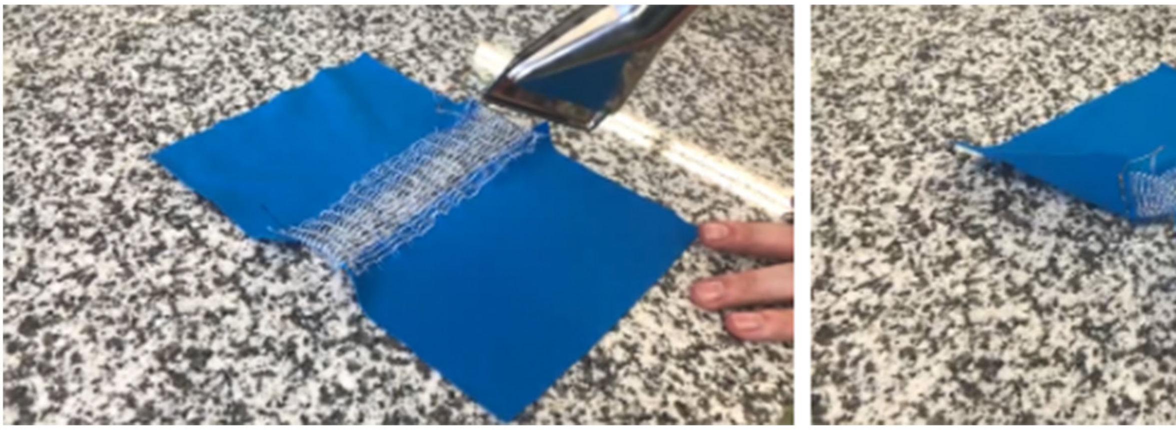


Figure A2.27 Lino weave. The development

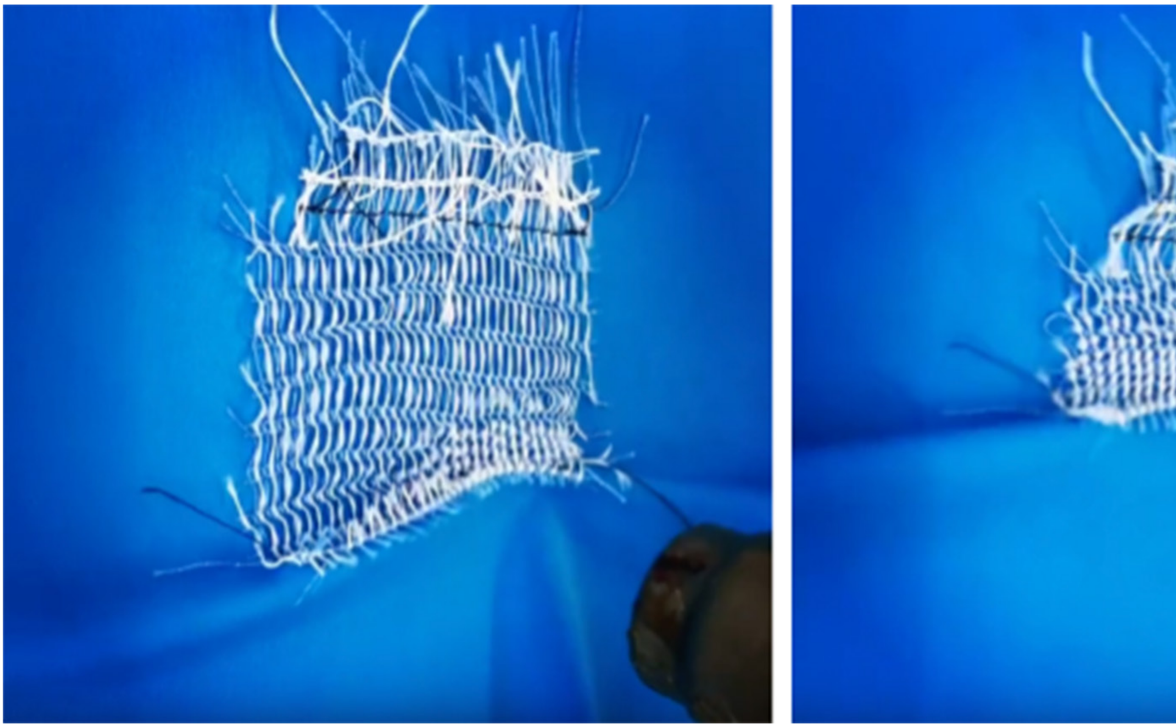
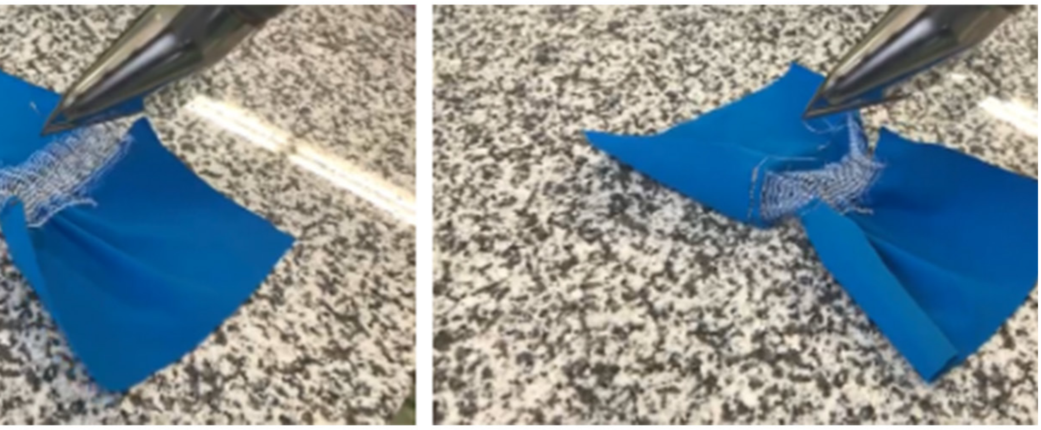
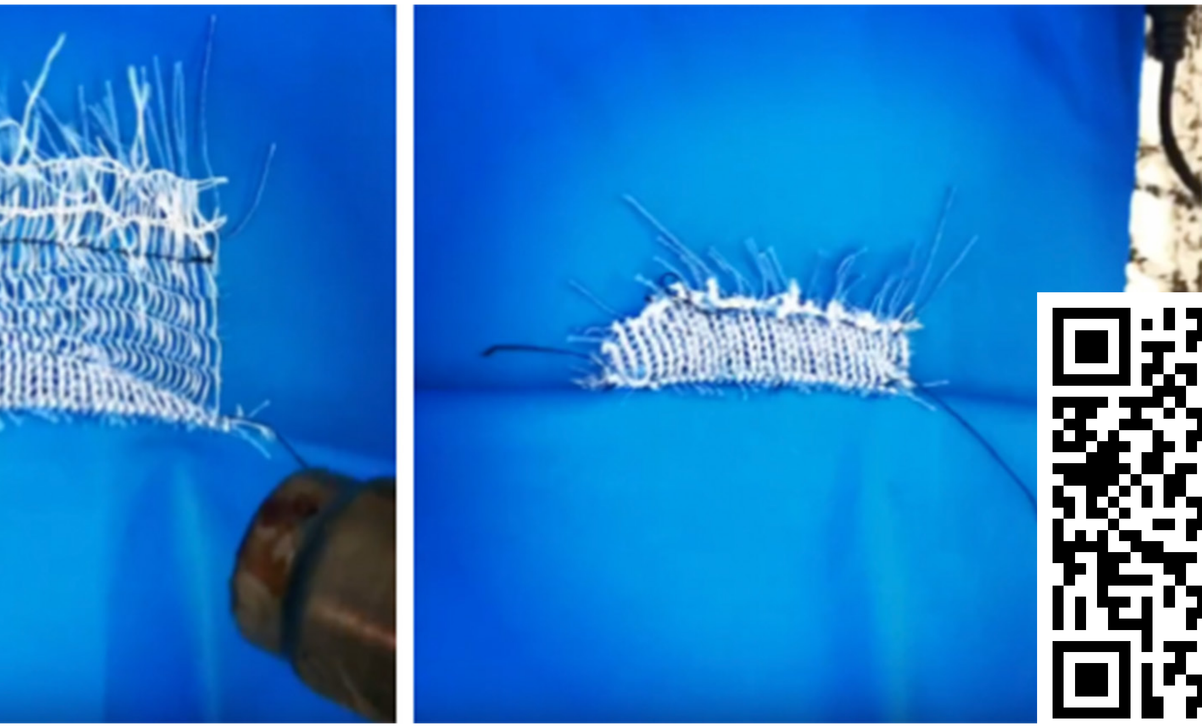


Figure A2.28 Lino weave. The development



of movement: Part 1 - Gather (Author's archive)



of movement: Part 2 - Pleat (Author's archive)

Figure A2.29 Lino weave. Visualising movement: A comparison (Author’s archive)

Figure A2.210 Surface ‘aesthetic’: Visualising movement
(Author’s archive)

Figure A2.211 Pemotex ribbon and Inox yarn: Manipulating ribbon shape (Author's archive)

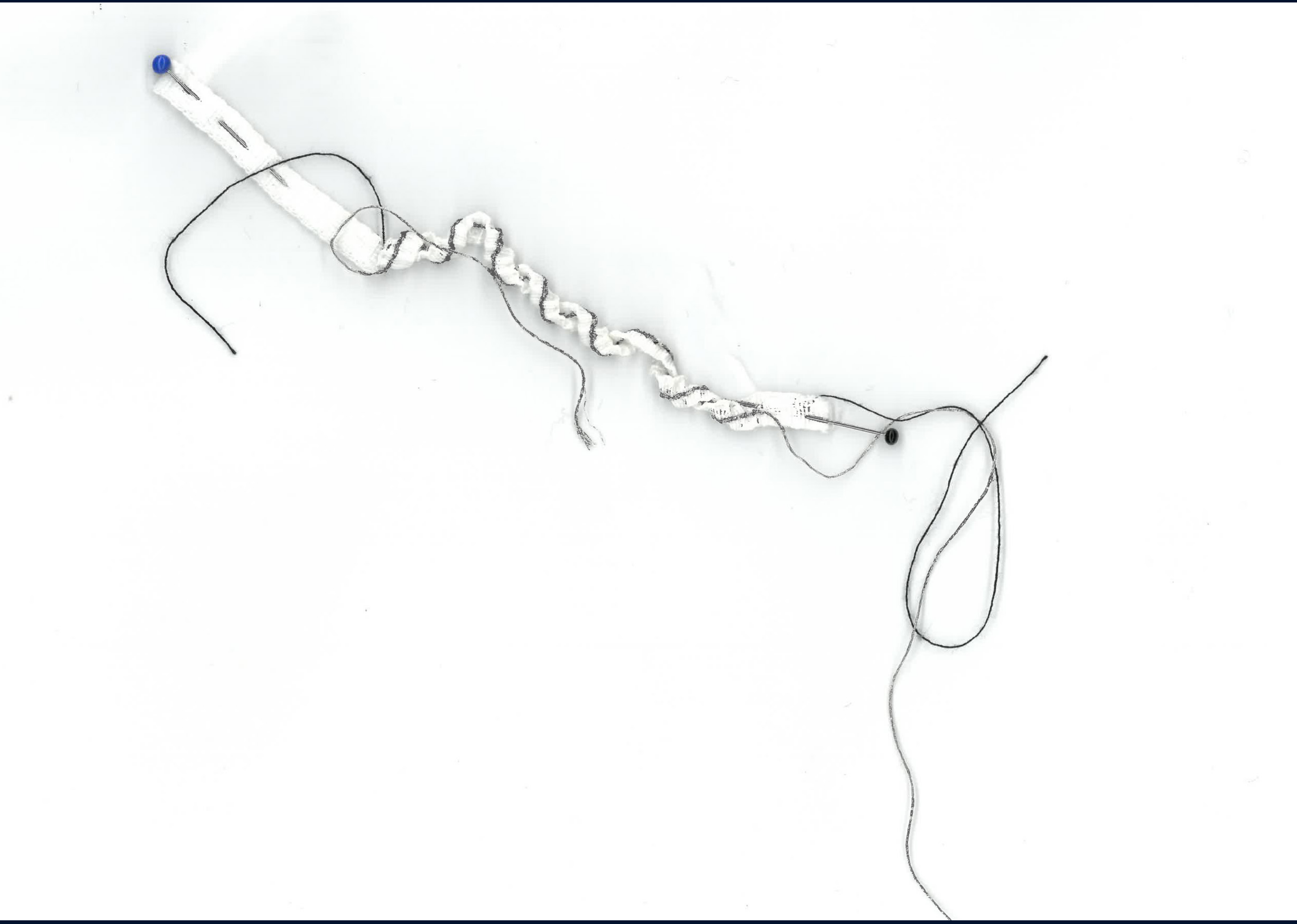


Figure A2.212 Pemotex ribbon and silver/ copper yarn: Enhancing ribbon manipulation (Author's archive)

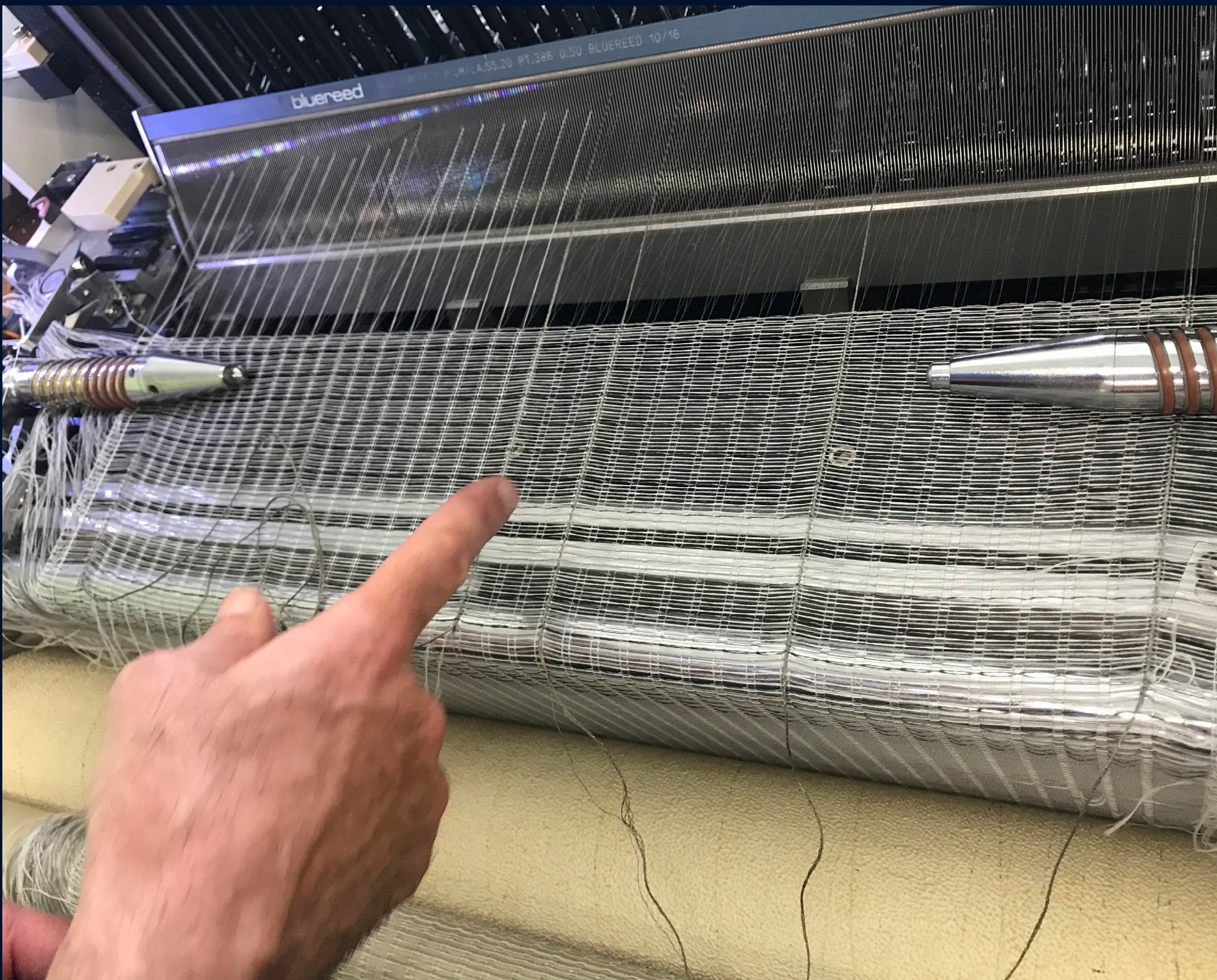
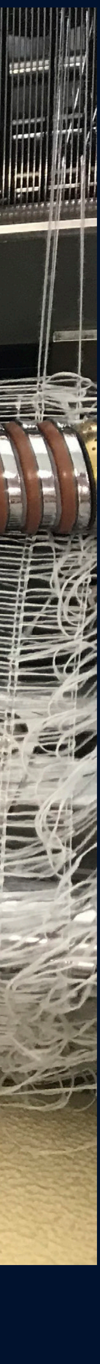


Figure A2.213 Weaving circuits using Inox
(Author's archive)



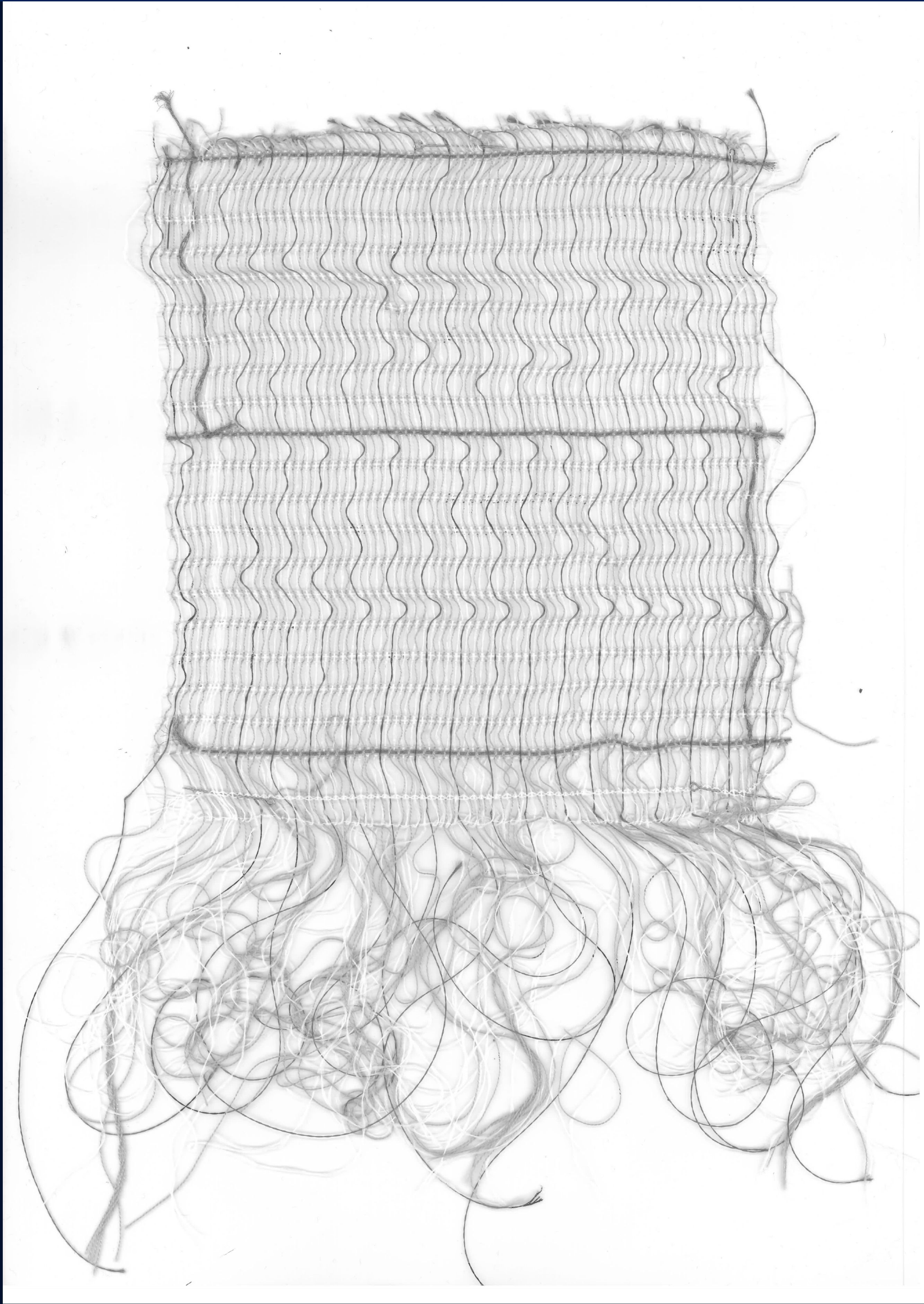


Figure A2.214 Pemotex, Inox, wool and nylon monofilament: Circuitry, iteration 1
(Design Research for Change Showcase: London Design Fair, 2019; Author’s archive)

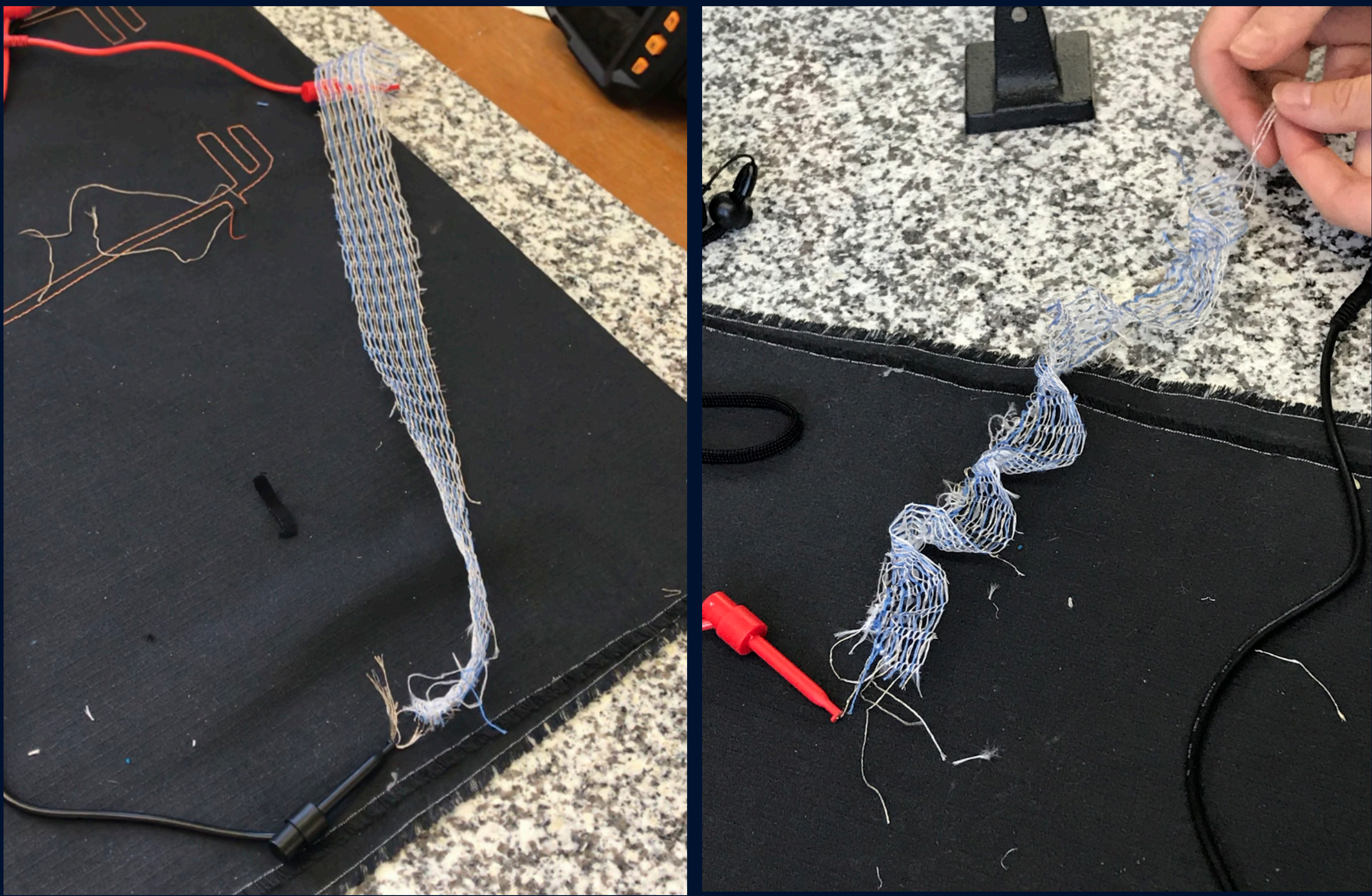


Figure A2.215 Manipulating textile shape, form and fit
(Pemotex, wool, nylon and copper:silver yarns)
Left: Before; Right: After (Author's archive)

Figure A2.216 Exhibit: View from afar (RCA: Work In Progress Show, 2019)

Figure A2.217 Preparing the circuitry
(Author's archive)

Figure A2.218 Ha
(Author's

and cuts: Close up
s archive)

Figure A2.219 Connecting the power source to the circuit
(Author’s archive)

Appendix 2.3 Concept limitations and considerations

Table A2.31: Methods for design and performance optimisation

Method	Key considerations
Utilising copolymers and composites	1) PVDF copolymers exhibit higher output than PVDF homopolymer (Parangusan et al., 2018). 2) Alternatively, ceramic-polymer composites combine beneficial attributes from both ceramic and polymer piezo materials to improve the energy density (Ue)[1]. 3) E.g. combining the use of BaTiO3 or PVDF (or its copolymers) with polymers (e.g. polypropylene) or alternatives (e.g. polystyrene) The actuator and bead casing may compose of a composite piezo material to optimise output performance. 4) However, combining piezo materials comes with several challenges; firstly with interface compatibility; secondly, the dispersion of fillers; and finally, poor electrical 'mismatch' (Ma et al. 2019). 5) Surface modification of inorganic fillers via, for example, silane coupling phosphonates and polymers (Zhang et al., 2017a; Zheng et al., 2018a) can help mitigate these issues.
Poling	1) Techniques such as stretching, fiber formation at given temperatures including melt spinning (Hadimani et al., 2014) or the combination of stretching and poling (Ali et al., 2011; Park et al., 2019) may be employed to increase the β- phase content of such polymers.
Fillers	1) When the poling field is removed, the piezoelectric material exhibits remnant polarization and permanent strain or permanent change in the dimensions (Dahiya and Valle 2013). 2) The mechanical stretching and electrospinning via thermal motion can result in the partial depolarization of PVDF-HFP films and fibers. This can be overcome by introducing nanofillers to stabilize the β-phase nanocrystals (Kanik et al., 2014; Baji et al., 2011; Liu et al., 2017); e.g. the use of NiO@SiO2 in Dutta et al. (2018)[2]. 3) Increasing the NiO@SiO2 nanoparticles from 0-16 wt% increases beta phase fraction from just ~30% to ~75% respectively. The addition of further fillers aggregates all the beta crystals into beta polymorph from alpha polymorph until the point of saturation, which is observed at 10 wt% within this study (Dutta et al., 2018). 4) The melting temperature of the sample increase with increased loading of NiO@SiO2 compared to that of 'neat' PVDF films. This is ascribed to the change in degree of crystallinity and homogeneity in submolecular structures, supporting the formation of the electroactive beta phase. This increase in melting point is desirable for applications to garments where aftercare conditions such as ironing may involve high temperatures.

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Should the reader be interested in receiving the information please contact the author at: laura.salisbury@rca.ac.uk].

Figure. A2.32. Considering multiple beads

[1] Energy density (Ue) is strongly dominated by relative permittivity (εr) and breakdown strength (Eb). Enhancing the εr and Eb simultaneously improves the Ue (Ma et al., 2019). Ferroelectric polymers (e.g. PVDF) typically exhibit high εr, but have low Eb. Dielectric ceramics (e.g. $BaTiO_3$) similarly display a high εr. Having said this, commercially available biaxial-oriented polypropylene typically exhibits very high Eb (~600 MV m^{-1}) but with a low εr of ~2.2 (Hu et al., 2018). Combining $BaTiO_3$/PP and PVDF is seen as beneficial for increasing Ue.
[2] Alternative fillers may be used e.g. cellulose nanocrystals (Ponnamma et al., 2019b) or graphene (Yaqoob et al., 2017)

Appendix 2.4

Comparative analysis of output performances of piezo materials

Category	Method of construction	Output current (mA/A)	Output voltage (mV/V)
SingleYarn	Melt-extruded with poling	-	2.2V
	Melt- spinning with poling	-	25mV
	Continuous nanofiber yarn electrospinning	-	500mV
	Continuous nanofiber yarn electrospinning	-	500-600n
	Electrospinning with poling	-	520mV
Textile (multiple yarns)	-	1.05µA (2x1 rib - 30% stretch)	23.5V (2x1 rib 30% stre
		-	12V (Double b 20% stre
		-	2V (Single be 10% stre
	Continuous melt-spinning	-	9.93 ±0.4
	-	-	61.96 V (384.4µV

Table A2.41: Comparative analysis of output performances

	Compressive/ tensile force applied	Frequency of applied force *(Hz)*	Source
	~0.1MPa/ ~10N (1.02kg/cm2 from height of 5cm)	-	Hadimani et al., 2013
	-	-	Matsouka et al., 2016
	-	-	Park et al., 2019
nV	1 MPa/ ~100 N	0.5	Ali et al., 2012
	-	-	Gao et al., 2018
- tch)	-	-	Kwak et al., 2017
ed - tch)	-	-	
ed - tch)	-	-	
7V	0.002-0.10MPa/ ~0.2-1 N	-	Soin et al., 2014
/ W)	Load resistance of 1GΩ	-	Liu et al., 2016

Category	Method of construction	Output current *(mA/A)*	Output voltage[1] *(mV/V)*
Non-woven: Films	Screen printing and cold isostatic press	Cotton:	~30V (14 J/m³ energy densit
		Polyester -cotton:	~25V (22 J/m³)
		Kermel:	~20V (34 J/m³)
	Electrospun film	1.9 µA	5.5-12V
Non-woven: Rubbery matrices	Shear dispersion and vulcanization	0.4µA	8V
	Spin coated	2.5µA	10V
	-	700µA	120V
		250µA	55V

	Compressive/ tensile force applied	Frequency of applied force *(Hz)*	Source
ty)	0.0008MPa/ ~0.08N (Load resistance of 30MΩ)	1	Almusallam et al., 2017
	(50MΩ)		
	(50MΩ)		
	-	-	Ponnamma et al., 2019b
	-	0.7	Chou et al., 2018
	0.01-0.04MPa/ ~1-4N	-	Yaqoob et al., 2017
	-	50	Jung et al., 2015
	-	35	

[1] Studies do not report implications of aftercare processes. Zhao et al., (2016) demonstrate that the short-circuit current density was significantly reduced after the first wash (from ≈ +/-13mA/m^2 to ≈ +/-5mA/m^2). The degeneration was due to yarn shrinkage and untwisting which changes the properties of the contact surfaces. This can be overcome somewhat by attending to the type of twist or braiding techniques whereby the degree of contact between the yarns can be manipulated.

Appendix 2.5 Sampling: equipment and resources

Cash-wool was used to knit[1] 30 samples of differing textile structure. The tension was adjusted accordingly, via observational study and 'trial and error'.
For Samples in Table 7.8, electrospun PVDF nanofiber films (supplied by Inovenso) were applied to the surface of the textile using 'heat 'n' bond' textile adhesive (sandwiched between the nanofiber film and textile), with an industrial steam iron (set to 100°C). No steam was used. The iron was placed on top of the film and full body weight pressure was applied for varying amounts of time.

On a random number of samples, a conductive ink/ paint (sourced from Bare Conductive) was applied in single strips by squeezing the tube and brushing it into a more uniform layer. Unlike samples 1-30, samples 31 to 60 were digitally knit.

Equipment and Yarn

Table A2.51: A summary of machines used for the relevant Samples

Sample numbers	Machine	Gauge
1-30	Dubied	12
31-45	Sheima Seiki (SES 122.S)	14
46-60	Stoll CMS ADF 32 W multigauge	14

[1] Having previously trained in technical pattern and garment construction/ design, the researcher (Salisbury) learnt how to knit on a Dubied for the purposes of this study.
[2] Calculated as grams per 10km of length of yarn
[3] Calculated as the ratio of length in meters to mass in grams
[4] Elongation (30-31%); Shrinkage (4-8%); melting point (160°C)
[5] 0.08 mm melt extruded homopolymer

Table A2.52: A summary of yarns used in experiments for Sample Series I, II and III

Yarn name *(as stated in the text)*	**Colour**	**Composition**	**Count** *(Dtex)*[2]	**Metric count** *(Nm)*[3]	**Supplier**
PVDF (monofilament)[4]	Transparent	PVDF[5]	90	-	Monoswiss: Swicofil
Cotton- Zinc (ZTK 20/1)	White	ZnO infused cotton	-	20/1	Perma Corporation
Cotton- Zinc (34)	White	ZnO infused cotton	-	34/1	Perma Corporation
Inox (100%)	Grey	Stainless steel	120	-	Bart Francis
Cash-wool	Blue; Off-white	100% WV	-	2/30	Zegna Baruffa
Cash-metal	Off-white; Black	68% WS; 32% ME	-	25/2	Loro Piana: Divisione Filati
Lycra	White; Grey; Blue	Undisclosed amounts of Polyester and Polyurethane	-	1/65	Filati be.mi.va
Black Lycra	Black	unknown	-	2/50	E. Miroglio srl
Black Lycra (replacement yarn)	Black	unknown	-	2/50	Alpes Manifattura Fi
Solvron	White	PVA (72%: Al_2O_3; 28% SiO_2)	110	-	-

Appendix 2.6 Sample specification (Sample Series I, II & III)

Table A2.61: Sample specification (Digitally knit samples from Sample Series I

Sample number	Yarns	Textile structure	Carrier
31	Cash- metal (black)	Tubular	2
	Cash- metal (off-white)	Drop stitch	4
	Solvron[1]	Drop stitch	5
	Lycra	Tubular	1
	Cash-wool (blue)	Tubular	1
	Cash-wool (off-white)	Double bed	3
32	Cash- metal (black)	Tubular	2
	PVDF	Drop stitch	3
	Solvron[1]	Drop stitch	5
	Lycra	Tubular	1
	Cash-wool (blue)	Tubular	1
33 & 34	PVDF	Drop stitch; Half milano	4
	Solvron[1]	Drop stitch	5
	Cash-wool (blue)	Double bed	3
	Lycra	Tubular	1
	Cash-wool (blue)	Tubular	1

35	PVDF	Half milano	4
	Solvron[1]	Drop stitch	5
	Cash-wool (blue)	Double bed	3
	Cotton- Zinc	Half milano	4
	Lycra	Tubular	1
36	PVDF	Half milano	4
	Solvron[1]	Drop stitch	5
	Cash-wool (blue)	Double bed	3
	Cash- metal (off-white)	Half milano	4
	Lycra	Tubular	1

[1] Solvron is washed out in water, dissolving to form the drop stitch in a post sampling process

Table A2.62: Sample specification (Sample Series II, III)

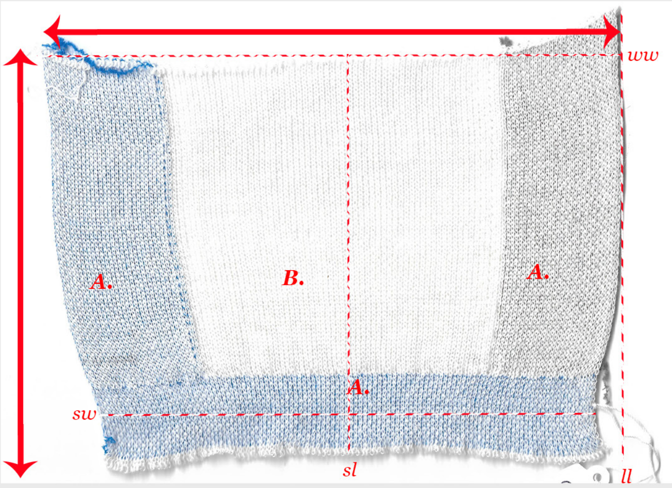
Sample number	Yarns	Textile structure
37	PVDF monofilament	Double bed
	Inox (100%)	Double bed
38	Section A: PVDF; Inox (100%); Lycra (white)	Double bed
	Section B: PVDF; Cash-metal; Lycra (white)	Double bed
39	Section A: PVDF; Cotton- Zinc (ZTK 20/1); Lycra (white)	Half milano (plated)
	Section B: PVDF; Cotton- Zinc (ZTK 20/1); Lycra (white)	Mock rib (plated)
40	Section A: PVDF; Cotton- Zinc (ZTK 20/1)	Half milano (plated)
	Section B: PVDF; Cotton- Zinc (ZTK 20/1)	Mock rib (plated)
41	PVDF; Cotton- Zinc (ZTK 20/1); Lycra (white)	Half cardigan (plated)
42	PVDF; Cotton- Zinc (ZTK 20/1); Lycra (white)	Cardigan (plated)
43	PVDF; Cotton- Zinc (ZTK 20/1); Lycra (white)	1x1 rib (plated)
44	PVDF; Cotton- Zinc (ZTK 20/1)	Inlay; tubular
45	PVDF; Cash-wool	Inlay; tubular
46	Section A: Nylon monofilament [test]; Cash-wool	Inlay; tubular
	Section B: Cash-wool; Lycra (white)	Double bed
47	Section A: Nylon monofilament [test]; Cash-wool	Inlay; tubular
	Section B: Cash-wool; Lycra (white)	Tubular; inlay
48	Section A: Nylon monofilament [test]; Cash-wool	Inlay; tubular
	Section B: Cash-wool; Lycra (white)	Tubular; inlay
	Section C: Wool (pink)	Intarsia

Tension	Tension change 1	Tension change 2	Stretch		Shrinkage after steaming (at 90 degrees)	
			Warp (%)	Weft (%)	Warp (%)	Weft (%)
-	-	-	100	45	none	none
-	-	-				
-	-	-	105	50	8	10
-	-	-	125	50	11	14
-	-	-	110	140	36	36
-	-	-	100	80	36	39
-	-	-	80	60	10	16
-	-	-	85	60	24	15
-	-	-	130	170	40	16
-	-	-	210	200	41.5	17
-	-	-	165	170	37.5	17
-	-	-	70	80	20	5
-	-	-	75	45	0	3
-	-	-	150	40	-	-
-	-	-				
-	-	-	80	25	-	-
-	-	-				
-	-	-	65	30	-	-
-	-	-				
-	-	-				

49	Section A: Cotton- Zinc (ZTK 20/1); Cotton- Zinc 34	Tubular (plated)
	Section B: Cotton- Zinc (ZTK 20/1); Lycra (white)	Tubula (plated
	Section A: Lycra (blue and grey)	Inlay (tuck every stitc
	Section B: PVDF	Inlay (tuck every stitc
50	Section A&B: Navy elastane	Tubular
	Section A: Lycra (blue and grey)	Inlay plat
	Section B: PVDF	Inlay (tuck every stitc
51	Cotton- Zinc (ZTK 20/1); PVDF	Interlocl
52	Cotton- Zinc (ZTK 20/1); Lycra (white); PVDF	Interlock; Tu (plated)
53	PVDF; Cotton- Zinc (ZTK 20/1); Lycra (white)	Interlock; Va float stitc
54	Cotton- Zinc (ZTK 20/1)	Interloc
	Lycra (white); PVDF	Inlay
55	Cotton- Zinc (34); Lycra (white)	Tubular inte
	PVDF	Inlay
56	Cotton- Zinc (34); Lycra (white)	Tubular inter
	PVDF	Inlay
57	Cotton- Zinc (34); Lycra (white)	Tubular interlocl
	PVDF	Inlay (tuck every other s
58	Black Lycra	Tubular inte
	PVDF	Inlay (tuck on other stitc
59	Black Lycra	Tubular Interlocl
	PVDF	Inlay (tuck every stitc
60	Black Lycra	Tubular Interlocl
	PVDF	Inlay (tuck on other stitc

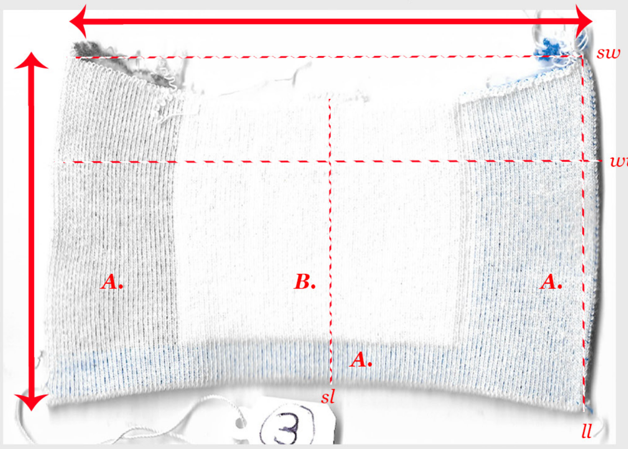
r)	12	-	-	100	110	-	-
r)	9	-	-				
on ch)	12	-	-				
on ch)	9	-	-				
r	11	-	-	100	120	-	-
ing	8	-	-				
on ch)	8	-	-				
k	9.5	-	-	90	50	-	-
bular)	10	-	-	70	60	-	-
aried ch	10.5	-	-	90	60	-	-
k	11 (Sample 11A)	10 (Sample 11B)	9.5 (Sample 11c)	95	67	-	-
	8.5	8	8				
erlock	9.5 (Section B)	10.5 (Section A)	-	50	100	-	-
	8	8	-	90	100	-	-
lock	9.5	-	-	40	70	-	-
	8	-	-				
r k	10.5	11.5	-	70	100	-	-
k on stitch)	8	8	-				
rlock	10.5	-	-	40	100	-	-
every ch)	7	-	-				
r	11	-	-	60	100	-	-
k	10						
on ch)	8	-	-				
r	11	-	-	70	70	-	-
k	10						
every ch)	8	-	-				

SAMPLE **A. Tubular spacer**



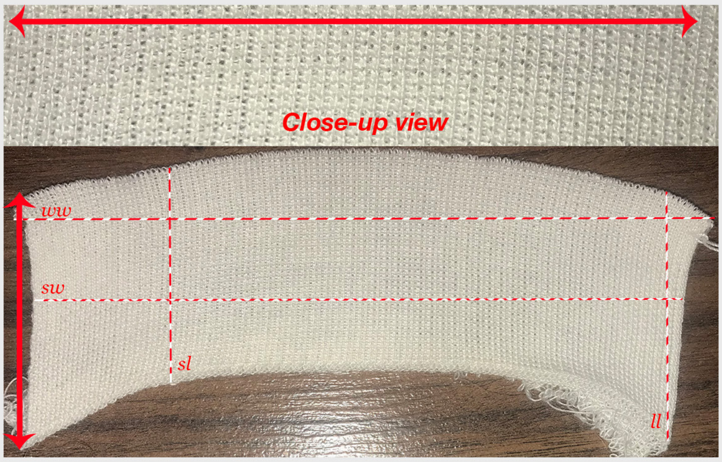
Widest width (ww): 16.5cm *Shortest width (sw): 14cm*
Longest length (ll): 13cm *Shortest length (sl): 11.5cm*

SAMPLE **B. Tubular spacer**



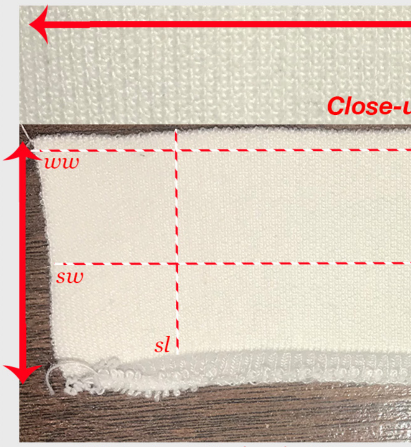
Widest width (ww): 12cm *Shortest width (sw): 11cm*
Longest length (ll): 7.5cm *Shortest length (sl): 6cm*

SAMPLE **E. Tubular Interlock**



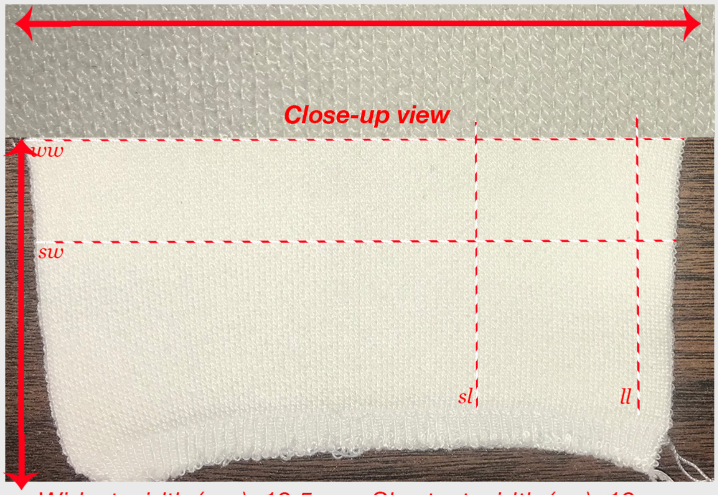
Widest width (ww): 16cm *Shortest width (sw): 15cm*
Longest length (ll): 5.5cm *Shortest length (sl): 5cm*

SAMPLE **F. Interlock**



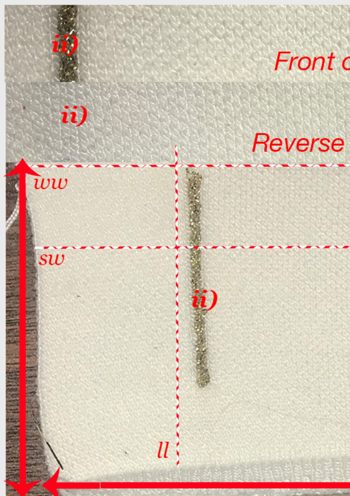
Widest width (ww): 13.5cm
Longest length (ll): 4.5cm

SAMPLE **H. Interlock with Float stitch**



Widest width (ww): 12.5cm *Shortest width (sw): 12cm*
Longest length (ll): 6cm *Shortest length (sl): 5.5cm*

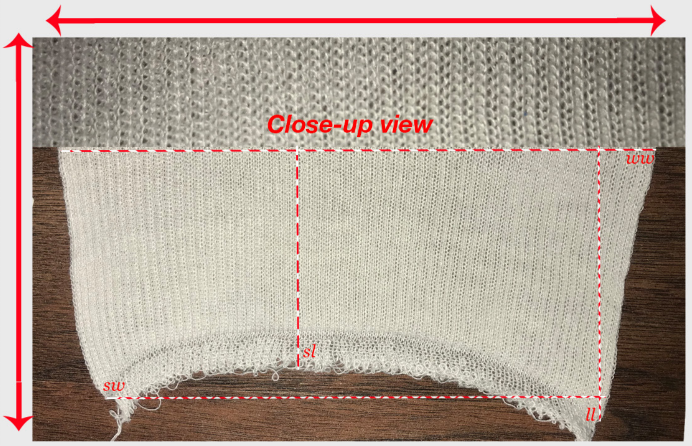
SAMPLE **Ji. Interloc**



Widest width (ww): 12cm S
Longest length (ll): 6cm

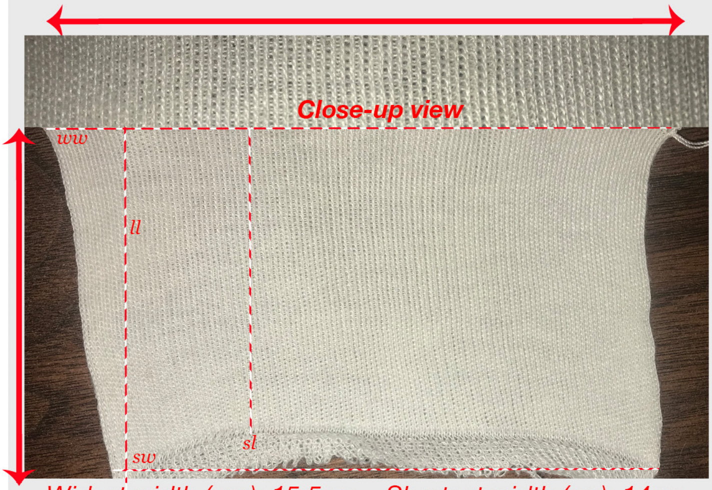
Figure A2.63a: Photographic compilation of 'Additional Samples Series III' and key measuremen

SAMPLE **C. Interlock**



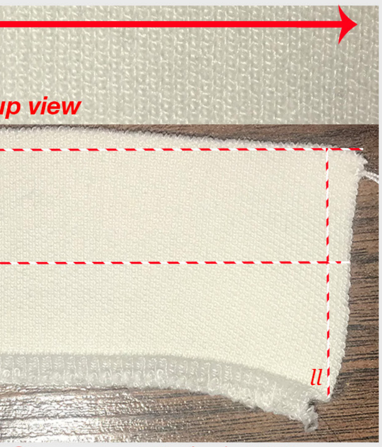
Widest width (ww): 20.5cm *Shortest width (sw): 16cm*
Longest length (ll): 12cm *Shortest length (sl): 10cm*

SAMPLE **D. Interlock**



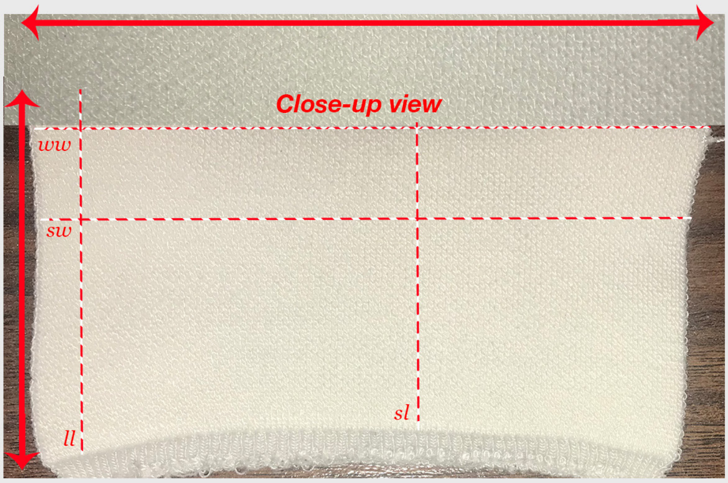
Widest width (ww): 15.5cm *Shortest width (sw): 14cm*
Longest length (ll): 9.5cm *Shortest length (sl): 8cm*

with Float stitch



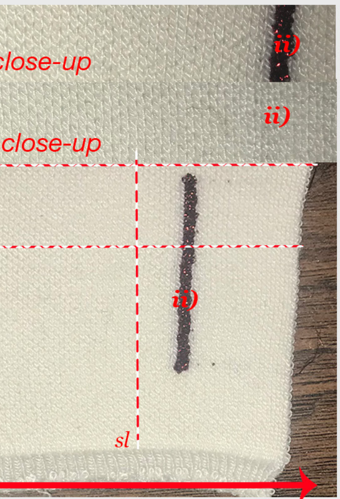
Shortest width (sw): 12.5cm
Shortest length (sl): 4cm

SAMPLE **G. Interlock with Float stitch**



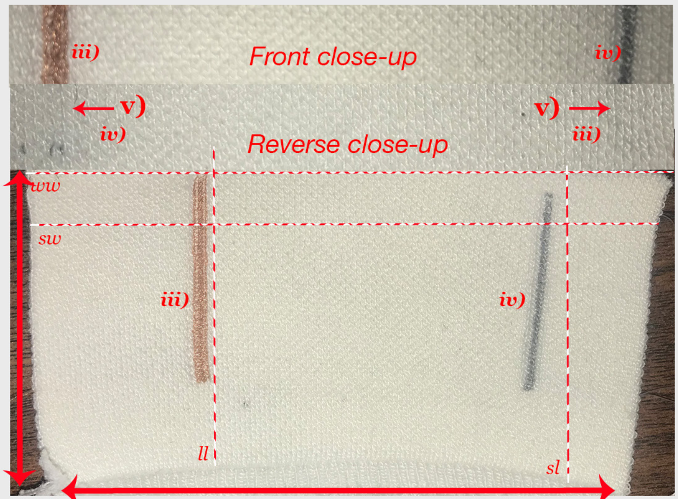
Widest width (ww): 12.5cm *Shortest width (sw): 12cm*
Longest length (ll): 6.5cm *Shortest length (sl): 5.5cm*

k with Float stitch



hortest width (sw): 11.5cm
Shortest length (sl): 5.5cm

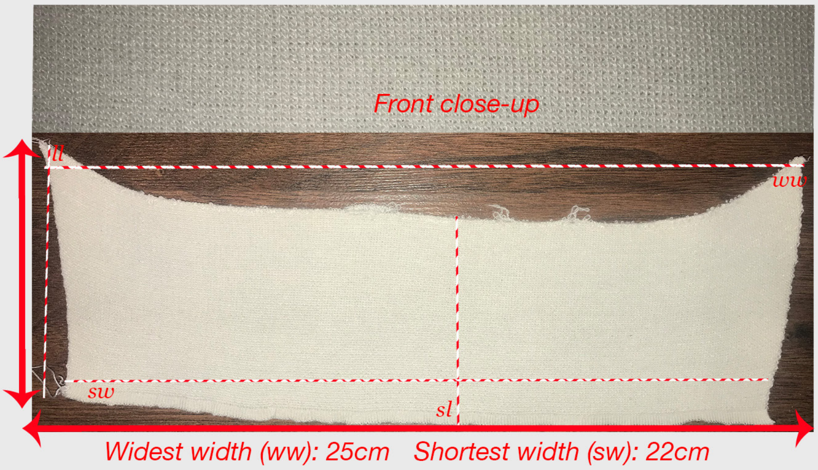
SAMPLE **Kiii. Interlock with Float stitch**



Widest width (ww): 12cm *Shortest width (sw): 11.5cm*
Longest length (ll): 6cm *Shortest length (sl): 5.75cm*

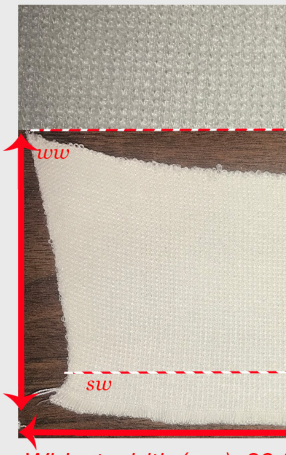
ts (Author's archive)

SAMPLE **Miii. Interlock Spacer**



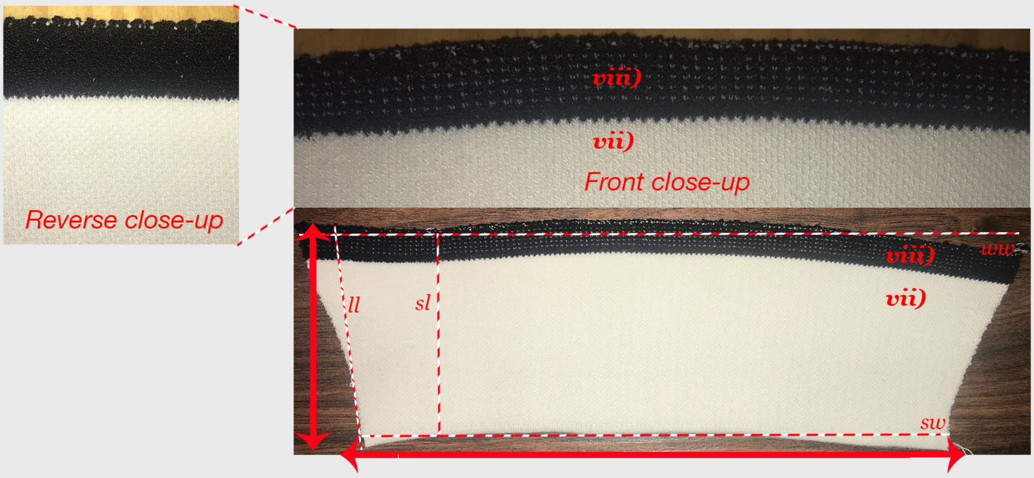
Widest width (ww): 25cm Shortest width (sw): 22cm
Longest length (ll): 10.5cm Shortest length (sl): 9cm

SAMPLE N

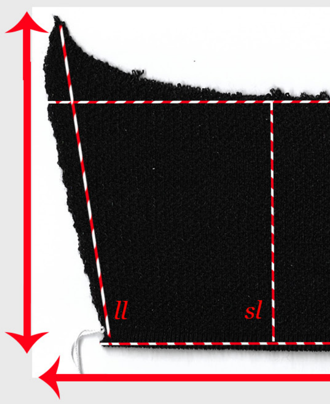


Widest width (ww): 32.5
Longest length (ll): 11.

SAMPLE **Q. Interlock Spacer**



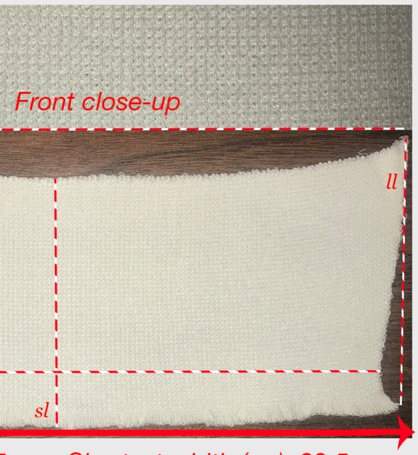
Widest width (ww): 31cm Shortest width (sw): 24.5cm
Longest length (ll): 9.5cm Shortest length (sl): 8.5cm



Widest width (w
Longest len

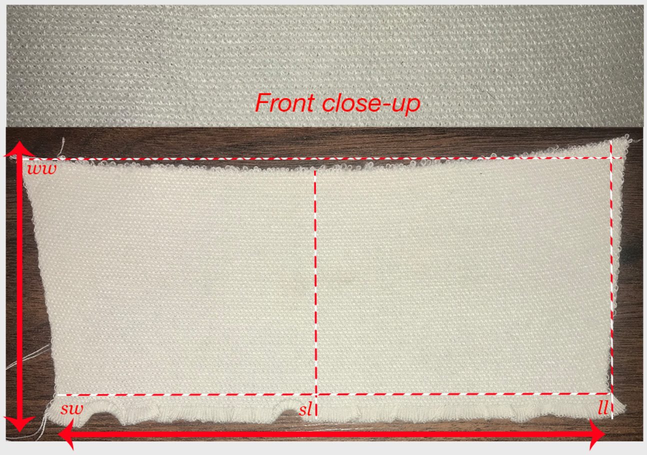
Figure A2.63b: Photographic compilation of ‘Additional Samples Series III’ and key measuremen

N. Interlock Spacer**



5cm Shortest width (sw): 29.5cm
5cm Shortest length (sl): 8.5cm

SAMPLE **P. Interlock Spacer**



Widest width (ww): 23cm Shortest width (sw): 21cm
Longest length (ll): 9.5cm Shortest length (sl): 10.5cm

SAMPLE **Rii. Interlock Spacer**

w): 26cm Shortest width (sw): 21.5cm
gth (ll): 9cm Shortest length (sl): 7cm

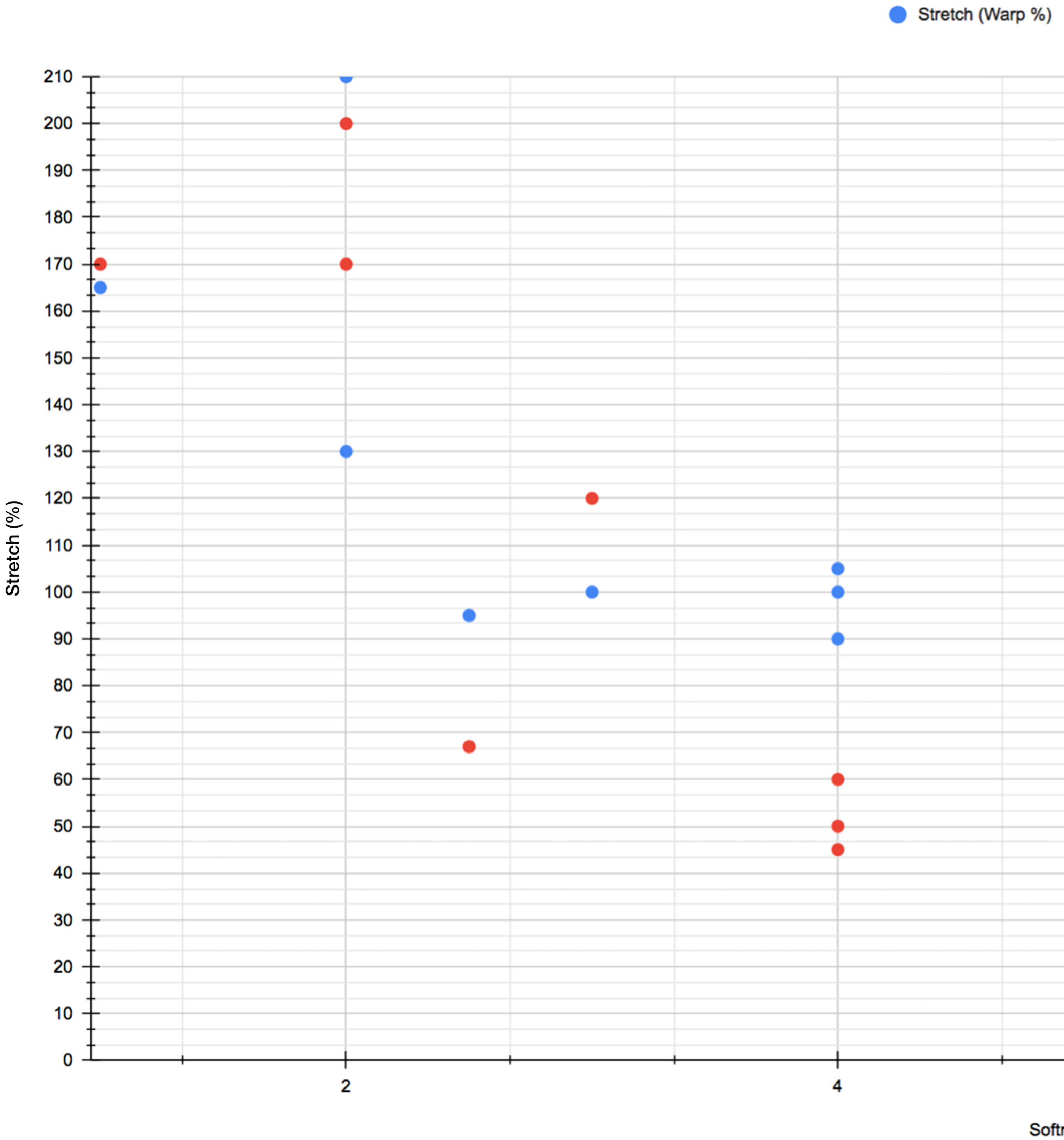
Front close-up

ts (Author's archive)

Sample number	Yarns	Textile structure	Tension	Tension change 1	Tension change 2
A	Cotton- Zinc (ZTK 20/1); Cotton- Zinc 34	Tubular (plated)	12	-	-
	PVDF; Lycra (blue and grey)	Inlay (tuck at every stitch)	9	-	-
B	Cotton- Zinc (ZTK 20/1); Cotton- Zinc 34; Lycra (white)	Tubular (plated)	11	-	-
	PVDF; Lycra (blue and grey)	Inlay (tuck at every stitch)	8- PVDF; 11- Lycra	-	-
C	Cotton- Zinc (ZTK 20/1)	Partial interlock (tuck at every stitch)	10	9.5	-
D	Cotton- Zinc (ZTK 20/1)	Interlock	9.5	-	-
E	PVDF; Cotton- Zinc (ZTK 20/1)	Tubular interlock (plated)	9.5	-	-
F; G; H	Cotton- Zinc (ZTK 20/1)	Interlock	9.5 (Sample F)	11.5 (Sample G)	11 (Sample H)
	Lycra (white); PVDF	Varied float stitch			
Ji	Cotton- Zinc (ZTK 20/1)	Interlock	11	-	-
	Lycra (white); PVDF	Varied float stitch	11		
	Lurex	Interlock	10		
Kiii	Cotton- Zinc (ZTK 20/1)	Interlock	11	-	-
	PVDF; Lycra (white)	Varied float stitch			
	85% Copper/ 15% Nylon (iii) 20% Inox/ 80% PES [Polyethersulfone] (iv)	Interlock	9		
Miii; N; P	Cotton- Zinc (ZTK 20/1)	Tubular interlock	9.5 (Sample Miii)	10.5 (Sample N)	11 (Sample P)
	PVDF; Lycra (white)	Inlay	8	-	-
Q	(Section A) Cotton- Zinc (ZTK 20/1); Lycra (white) (Section B) changed to Black Lycra; Lycra (white)	Tubular interlock	10.5	-	-
	PVDF; Lycra (white)	Inlay (tuck at every other stitch)	7	-	-

Rii; S	Black Lycra	Tubular	11 (Sample Rii)	10 (Sample S)	-
		Interlock	10 (Sample Rii)	11 (Sample S)	
	PVDF	Inlay (tuck on every stitch)	7	7	
T	Black Lycra (replacement yarn)	Tubular	11	-	-
		Interlock	10		
	PVDF	Inlay (tuck on every stitch)	7		
W	Black Lycra [Yarn consumption: 1542.31 mtrs (83.9%)]	Tubular	11 [Carrier: 14]	-	-
		Interlock	10 [Carrier: 14]		
	PVDF [Yarn consumption: 231.63 mtrs (12.6%)]	Inlay (tuck on every stitch)	7 [Carrier: 12]		
	Conductive tracks: 20% Inox/ 80% PES [Yarn consumption: 35.92 mtrs (2.2%)]	Interlock	8 [Carriers: 3-8]		
	Sensor pad: 20% Inox/ 80% PES [Yarn consumption: 5.86 mtrs (0.32%)]		11 [Carrier: 10]		
X; Y; Z	Black Lycra (replacement yarn)	Tubular	10	-	-
		Interlock	11		
	PVDF	Inlay (tuck at every stitch)	7		

Appendix 2.7 Sample specification ranking



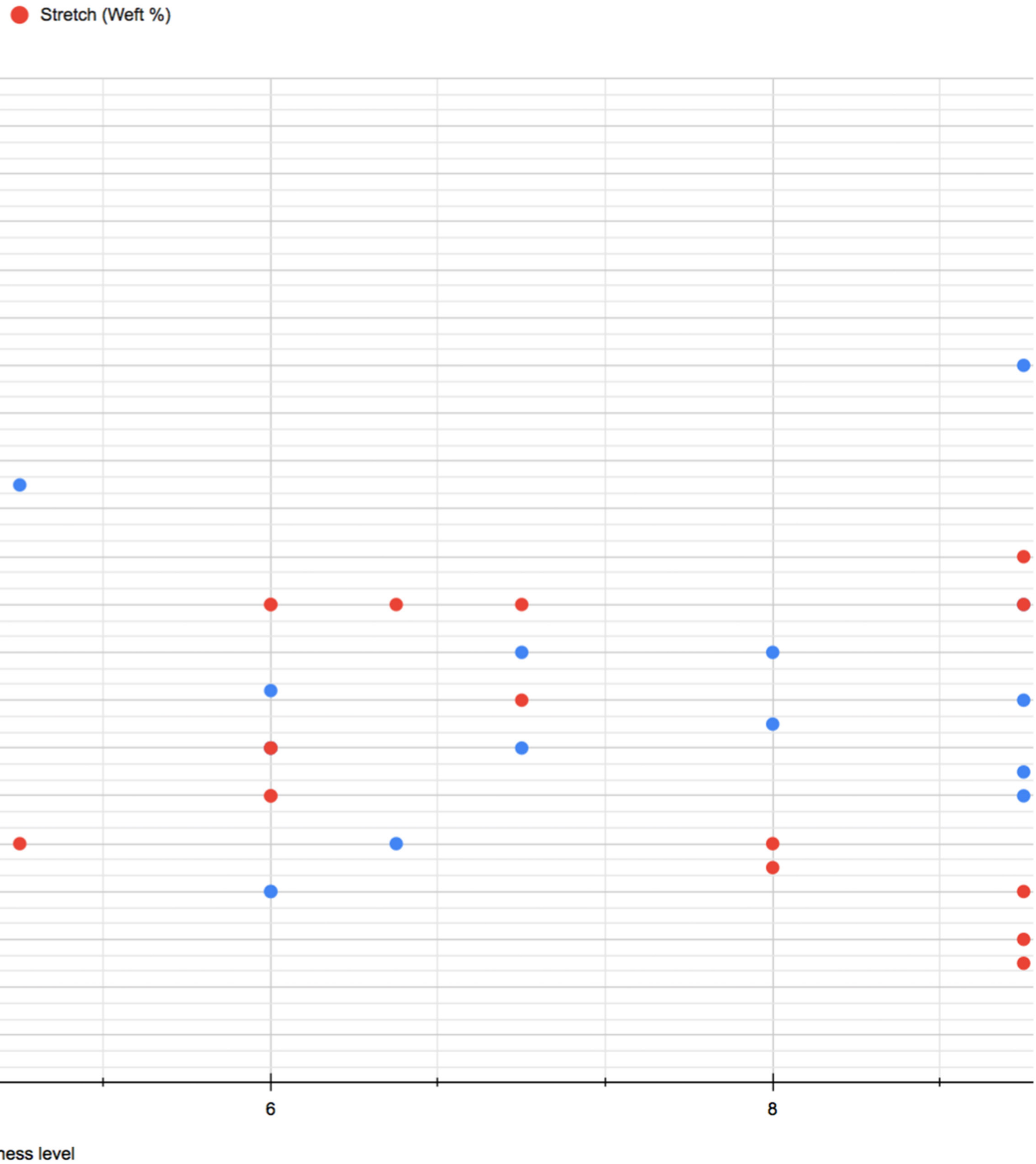
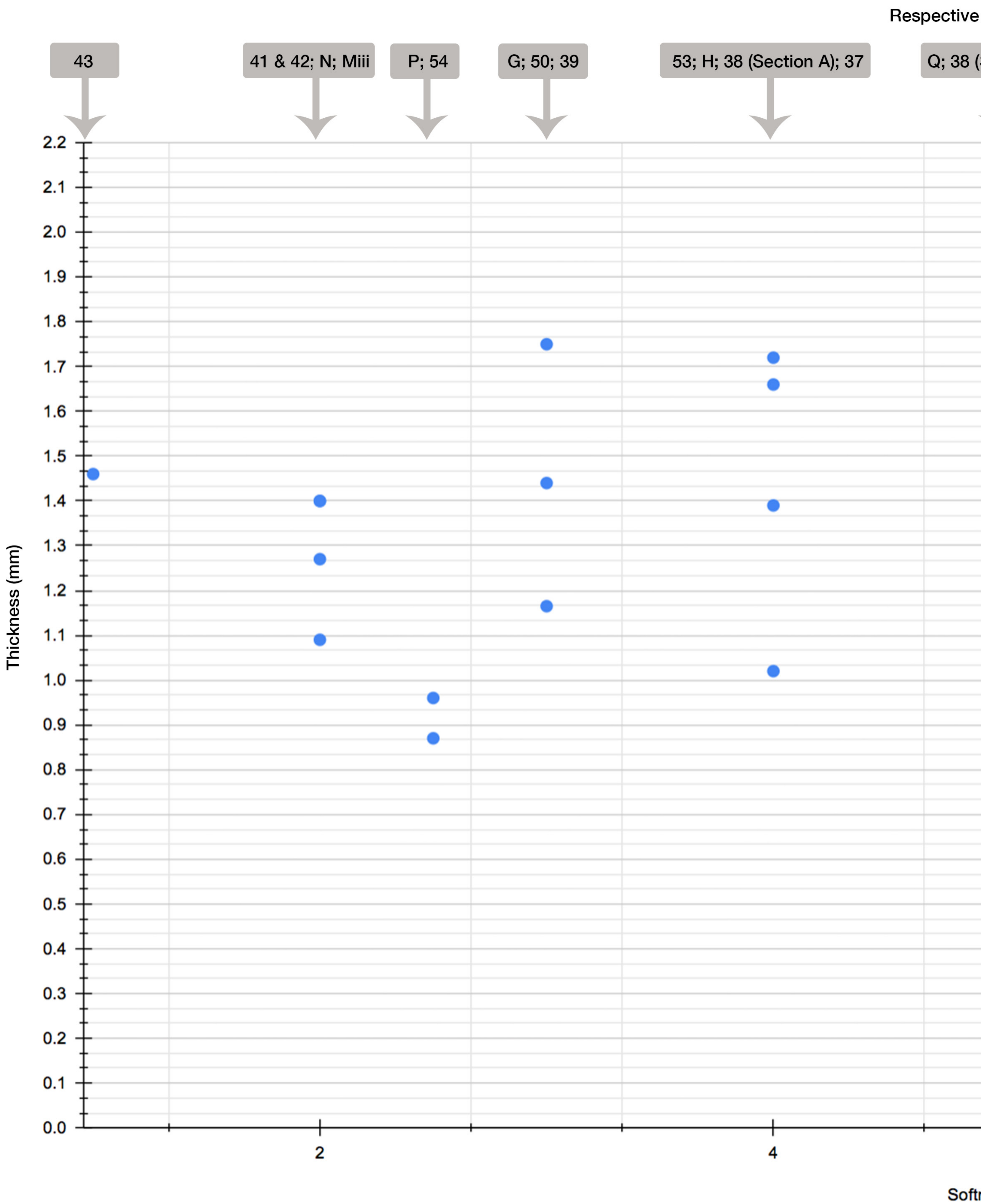


Figure A2.71 Individual sample values demonstrating the relationship between sample thickness and softness level



Respective
43
41 & 42; N; Miii
P; 54
G; 50; 39
53; H; 38 (Section A); 37
Q; 38 (
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Thickness (mm)
2
4

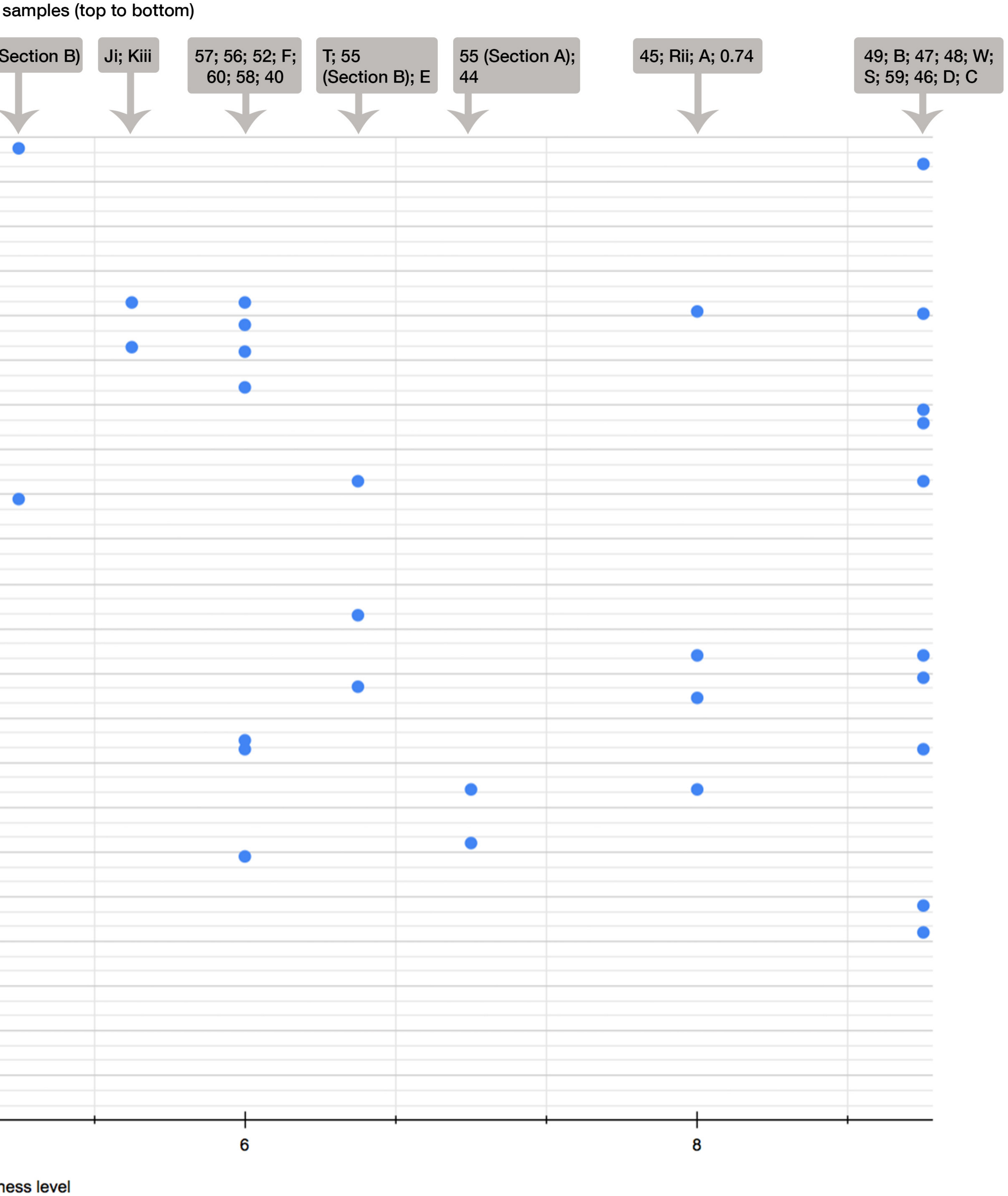


Figure A2.72 Individual sample values demonstrating the relationship between % stretch of the sample and softness level

Appendix 2.8

Yarn concept summary: Concepts 2 - 11

Table A2.81: Summary of considerations for further yarn concepts

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commercially s
Should the reader be interested in recei
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in the thesis was redacted due to its
ensitive nature.
ving the information please contact the
isbury@rca.ac.uk].

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commercially se
Should the reader be interested in recei
author at: laura.sal

in the thesis was redacted due to its
ensitive nature.
ving the information please contact the
isbury@rca.ac.uk].

[1] Raj et al., (2017) also use a non-conductive albeit unspecified core yarn
[2] The rotation of the ring collector causes the fibers to twist and 'whirl' inside it rather than being deposited on its surface. The airflow generated by the exhaust fan directs the nanofibers through the collector to the winder/ yarn spool which rotates at a slower speed and subsequently continuously collects the yarn produced.
[3] Park et al. (2019) shows that 260mV under 10% strain at 0.5Hz piezoelectric output may be obtained from a 4x4 braid containing 22 PVDF-TrFE yarns and 2 Cu wires; although the lengths of the braid was not specified

Appendix 2.9 Additional textile components
(responding to findings in Section 7.3.2.2, Chapter seven)

Supercapacitors exhibit higher power densities than batteries and so are considered more ideal for wearable circuitry. However, they require consideration for integrating into a garment. Zhang et al. (2018) has demonstrated a charge-storing pattern that can be incorporated into any garment, using traditional textile processes, in this case, embroidery. Further to this, Mirvakili et al. (2015) uses niobium nanowires as supercapacitors, delivering short, intense bursts of power reportedly superior in performance to carbon nanotubes.

A supercapacitor component may be constructed within energy harvesting components, therefore creating a two-in-one component. Through research into SPENGs, Chou et al. (2018) show that this can be integrated into one form. To improve the performance of supercapacitors, attention to surface area (Zhou et al., 2015). (Zhou et al., 2015) shows the development of a 3D flexible supercapacitor by introducing reduced graphene oxide to convert commercial cotton textiles by dip coating and annealing into *"free-standing, electrically conductive and electrochemically active"* fabric.
Building on this, Figure A2.91 displays a speculative design hypothesis for incorporating a supercapacitor into yarn and textile structures, paying attention to increasing the surface area available to collect charge.

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author at: laura.sal

Figure. A2.91 An overview of te

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isbury@rca.ac.uk].

xtile ‘components’ including (left to right) energy harvesting spacer; supercapacitor; switch and the ‘bead’

APPENDIX

3.0

Key supportive documents/ data

Appendix 3.1 Tables of anonymous participant data

Table A3.11: Female participants

Unique participant code	Stroke date and type *(if disclosed)*	Patient Pathway *(location of stroke care in hospital and community)*
AA		London
BB		London
CC		London
DD		London
EE		London
FF	Pulmonary embolism	London
GG		London
HH		London
JJ		London
KK	Aneurysm	London
LL		London
MM		London
NN		London

PP		London
QQ		London
RR		London
SS		London
WX		London
XY		London
YZ		London
ZA		Kent

Table A3.12: Male participants

Unique participant code	**Stroke date and type** *(if disclosed)*	**Patient Pathway** *(location of stroke care in hospital and community)*
TT		**London**
VV		**London**
WW		**Unknown**
AB	**Left frontal temporal hemorrhage** ***Dec. 2017***	**London**
BC	**Two strokes: left and right side** ***July. 2017***	**Southampton & London**
CD	**Right frontal lobe - Traumatic BI** ***Jan. 2016***	**Southampton & Plymouth**
DE	**Left thalamic bleed** ***2009***	**London**
EF	**Stroke on right-hand side brain**	**Unknown**
FG	**Stroke on left-hand side of brain**	**Unknown**
GH	**Basal ganglia hemorrhage** ***2015***	**London**
HJ	**Stroke on left-hand side of brain**	**Unknown**
JK		**London**
KL		**London**

LM	Traumatic brain injury	London
MN		Northern city & London
NP		London
PQ	Traumatic brain injury	London
QR		London & India
RS		London
ST		London
TV	Traumatic brain injury	London
VW		London
CE		London
BD		London
AC		London
DF		London

Appendix 3.2 NIHR UK Stroke workshop certificate

Stroke association

NHS National Institute for Health Research

BRITISH ASSOCIATION OF STROKE PHYSICIANS
ADVANCING STROKE MEDICINE

This certificate confirms that

Ms. Laura Salisbury

Attended the

NIHR UK Stroke Research Workshop

On

11th and 12th September 2018

RCP Activity Code Number 119642

Approved by the Federation of the Royal College of Physicians for
12 category 1 (external) CPD credits

Organiser's signature: ………………………………………….

Date Issued: 14th September 2018

Above: Figure A3.21 NIHR UK Stroke Research Workshop certificate;
Left:Figure. A3.31 Clinical observation contract (Part 1)

Appendix 3.3 Upper Limb Programme Observership Contracts

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[The following text that appeared in the thesis was redacted due to its sensitive nature regarding personal data].

Figure. A3.32 Clinical observation contract (Part 2)

[The following text that appeared in the thesis was redacted due to its sensitive nature regarding personal data].

Figure A3.33 Clinical observation contract (Part 3)

[The following text that appeared in the thesis was redacted due to its sensitive nature regarding personal data].

Figure. A3.34 Clinical observation contract (Part 4)

Appendix 3.4 Example Consent Form

The Clothing Project

Consent form

I **agree** that Headway and Laura Salisbury (Researcher) can use:

- My **name** (**first name only**)
- **Photograph**/ **video** image (my **face**)
- **Voice** recording (**sound** only)

My **information** will be **anonymous** (so **no one will know** it is me)

It will be used for **research** purposes:

- In **conferences** and **lectures**
- On the **internet**
- In **research papers**

To **help improve** the lives of others with a brain injury

(The **information sheet tells you more** about this research)

Name:
Date:
Signature:

Figure A3.41 Example consent form

Appendix 3.5 A contextual evaluation of neuromodulation and non-invasive brain stimulation [NIBS]

NIBS and deep brain stimulation [DBS] methods have been used in numerous approaches throughout medicine from modulating cognition and behaviour in adults and children (Vicario and Nitsche, 2013; Boggio et al., 2015; Palm et al., 2016), in Parkinson's Disease (Kuhn, 2006), to influencing states of recovery of motor training within stroke rehabilitation (Weightman et al., 2020; Carson and Buick, 2019) and as non-pharmacological treatments for chronic pain relief (Kellaway, 1946; Moisset and Lefaucheur, 2019).

Unlike deep brain stimulation (DBS), which requires surgical procedures to implant or apply stimulation devices within the body (Javedan and Shetter, 2003), NIBS uses a range of techniques outside the body, to deliver stimulation at various 'access points' such as the peripheral, median, vagus nerve or on the scalp. The positioning of the stimulation equipment impacts the degree of success in the delivery of the stimulation (Rossini et al., 2015).

Transcranial methods can face issues of having to deliver a stimulus across high resistance barriers including the *"scalp, skull, meninges and cerebrospinal fluid"* (ibid: 1073). Only a small proportion of the current is able to penetrate the brain and activate the neurons, requiring high voltages and activating local pain receptors in the skin which can be uncomfortable to experience (ibid). Alternatively, low-intensity stimulation approaches including tDCS (Nitsche and Paulus, 2000) can be used. When using a lower intensity, tDCS does not directly initiate action potentials but rather generates *"small changes in the membrane potential of cell bodies or the axonal terminations of neurons"* (Rossini et al., 2015: 1073).

Access via the peripheral nerve faces less resistance than transcranial methods. The stimulation parameters for access via the peripheral nerve has been shown to be *"relatively similar to those needed for [more invasive stimulation methods via the central nervous system]: short pulses with a duration of less than 1ms with an amplitude of few milliamperes"* (ibid).
In addition to this, when considering the positioning of the stimulation and the type of garment required to embed this in, it is considered more appropriate to use the peripheral nerve as the site of stimulation than using positions on the scalp by creating caps and hats (Fiedler et al., 2015) which can be limited in use by preference, context and season. Other entry points may be used around the body including via the spinal cord (Trent et al., 2020), neck and shoulder (Arnsei, 2019).

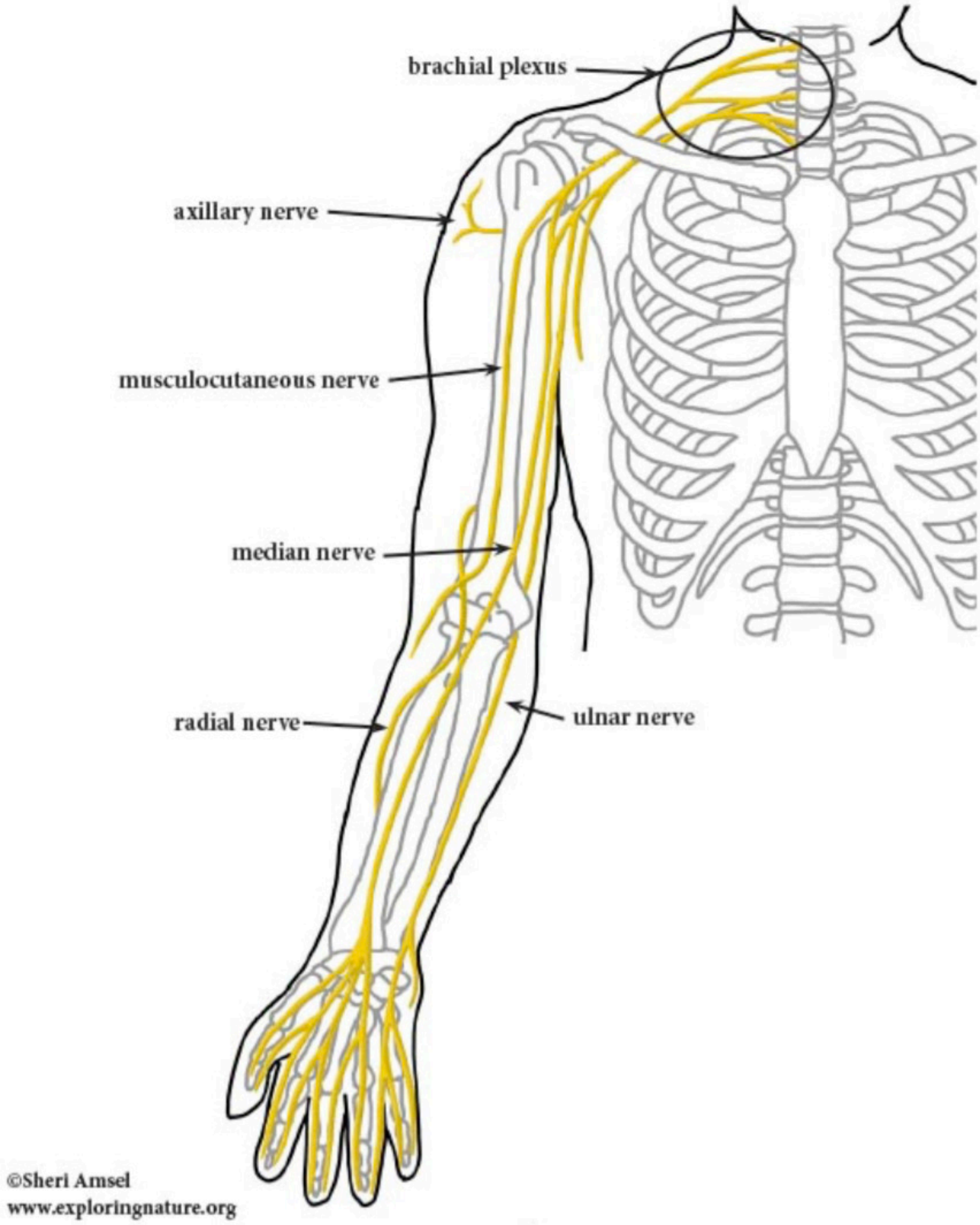


Figure. A3.51 An overview of the peripheral nerves of the neck, shoulders and upper limbs (Arnsei, 2019)

Appendix 3.6 Focus Group Question Guide

Fill in consent form before starting
Explain the session is to gather expert advice from them to develop the textile - re-iterate that no answer is incorrect and we are looking forward to gaining their honest opinion.
Don't disclose any more information at this stage - the function/ purpose of the textiles will be explained later on during the session.

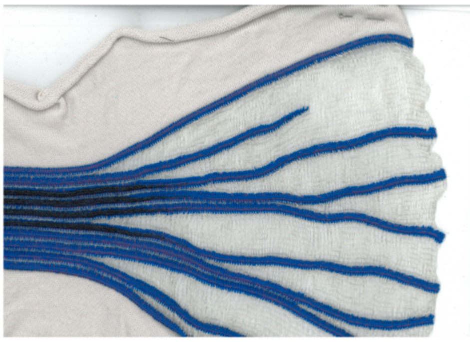
STEP 1

[show the first samples]

Which of the following textiles do you like and would consider wearing if they were made into a top?
Suggestions if struggling: how does it feel? How does it look?
Is there anything that it reminds you of or feels like?

STEP 2

What about this one [show sample below]



Suggestions if struggling: how does it feel? How does it look?
Is there anything that it reminds you of or feels like?

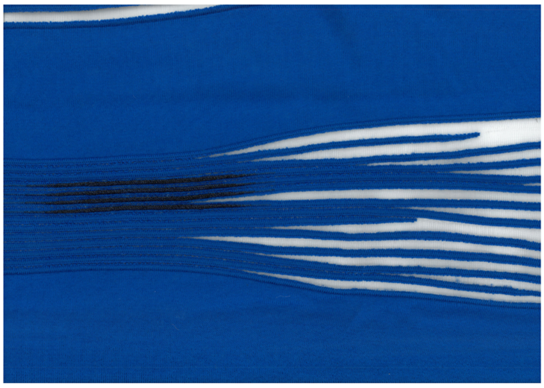
Which textile do you prefer?
Can you explain why?

Which textile do you least prefer?
Can you explain why?

What about the colour? If it was in a different colour would you wear it?
Why/ why not?

If they answered that they would wear then ask the following questions:
When would you wear this?
Suggestions if struggling: for the whole day - at night - at home - going shopping
----

STEP 3
[show next sample]



How about this?
Suggestions if struggling: how does it feel? How does it look?
Is there anything that it reminds you of or feels like?

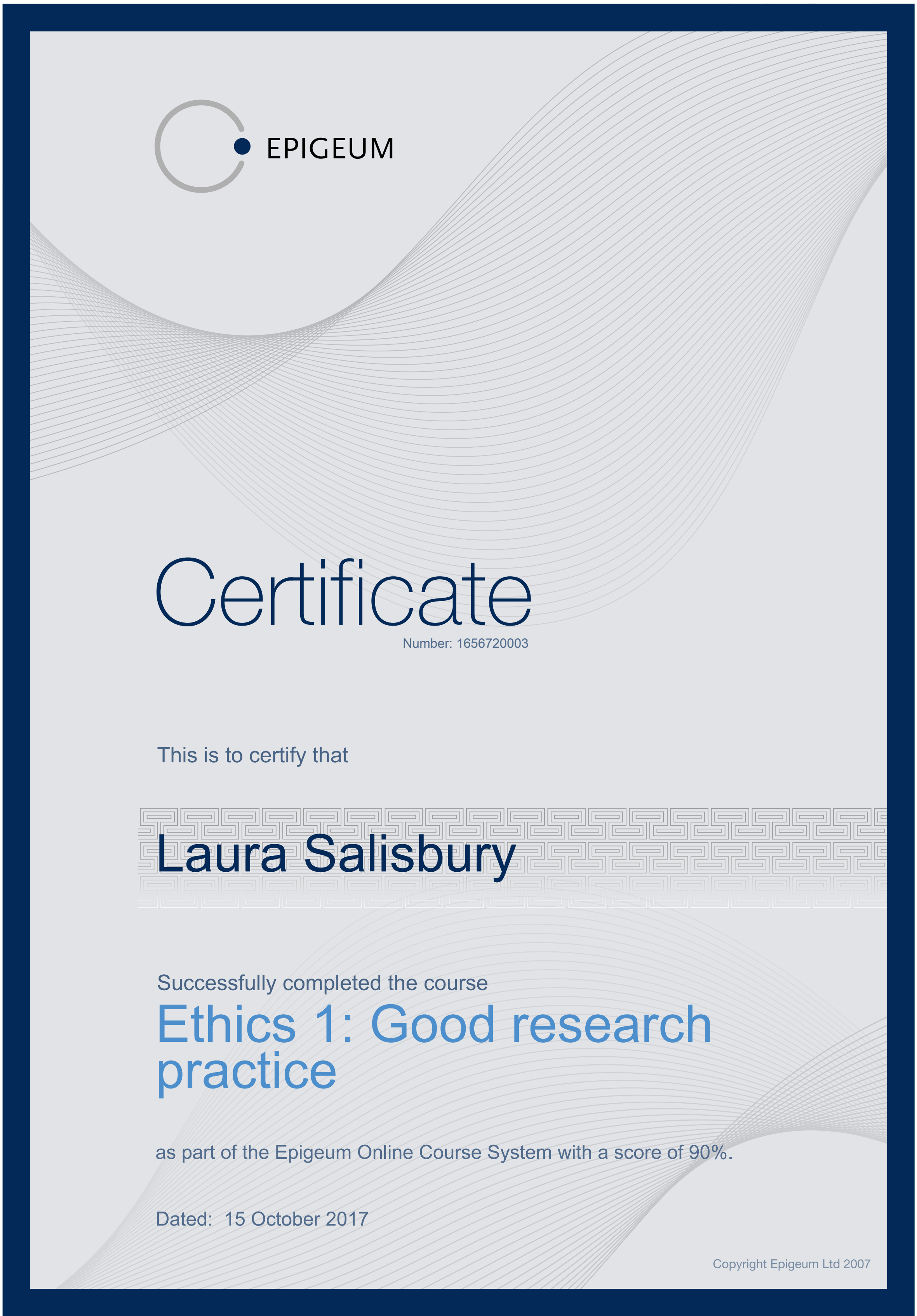
STEP 4
[explain what the textile is/ does]
What are your thoughts on this?
How do you feel about wearing this?

[show previous textile samples and ask the following questions:]
If you could change the type of textile it is made from, would you choose a different textile?
If yes, which one.
Can you explain your decision?

Thank the participants for their expert advice and opinions

Figure. A3.61 Focus group question guide

Appendix 3.7 Ethics training certificate


EPIGEUM

Certificate

Number: 1656720003

This is to certify that

Laura Salisbury

Successfully completed the course

Ethics 1: Good research practice

as part of the Epigeum Online Course System with a score of 90%.

Dated: 15 October 2017

Copyright Epigeum Ltd 2007

Figure. A3.71 Ethics certificate

Thesis ends.

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