Light my elbows: a cycling jacket incorporating electronic yarn

Light My Elbows: A Cycling Jacket Incorporating Electronic Yarn

DOROTHY HARDY[1], KATHERINE TOWNSEND[1], MATHOLO KGATUKE[1], ELOISE SALTER[1], TINA DOWNES[1], KAREN HARRIGAN[1], SUSAN ALLCOCK[2], TILAK DIAS[1], Nottingham Trent University, Nottingham, UK
[1] School of Art and Design
[2] School of Architecture, Design and the Built Environment

Fig. 1. The woven cycling jacket incorporating LEDs within electronic yarns in the elbows.

There is a need for illuminated cycle clothing that is comfortable and safe when cycling, and stylish to wear during other activities. It is particularly challenging to integrate lighting within textiles without compromising the drape and comfort of the textile structure. A team of electronics, textiles and fashion specialists was formed to design and make an illuminated jacket for use by cyclists. The jacket incorporates bespoke woven panels that integrate electronic yarns within the pattern. These were designed and made for this project, with fluorescent and retroreflective yarns also included in the weave. LEDs integrated within the electronic yarns illuminate the elbows of the jacket, without causing constraint or adding excess volume. The movement of the jacket elbows during cycling widens the body outline and makes the lighting eye-catching.

The collaboration between electronics and textiles experts overcame challenges including development of electrical circuitry designed specifically to fit into the jacket unobtrusively, without interfering with movement or rucksack straps. Electrical connections were required between the electronic yarns assimilated within the weave. Standard, rigid solder joints would have been difficult to form without damaging the cloth and would have been liable to breakage within the garment structure, so embroidery techniques were used to create flexible, conductive connections.

The illuminated jacket provides a working prototype, demonstrating the potential for further collaborative ventures in which electronics are integrated into garments that are stylish, functional and 'wearable'. Further interdisciplinary research will include the development of additional wearable prototypes that enhance safety and wellbeing, whilst addressing the recycling of the textiles and garments, including the safe separation and disposal of electronic yarn and other components that provide electrical functionality.

Additional Key Words and Phrases: Cycling, Safety, Clothing, Electronic textiles, Electronic yarn, LED, Light-emitting diode

1 INTRODUCTION

This project centred on the use of a particular type of electronic yarn known as E-yarn [1]. The research described here sought to find out how E-yarn could be incorporated into a practical and stylish garment. This paper explores the interactions and innovations required to design and make a cycling jacket incorporating E-yarn.

E-yarn is different from other types of electronic yarn and wires, because LEDs or sensors, plus a conductive core, are held within a textile sleeve. Alternative products include textile yarns covered in conductive material [2] and textile-covered wires [3]. These require separate attachment to semiconductor dies, rather than containing the dies within the yarn structure. The inclusion of semiconductor dies within E-yarn

Publisher: Loughborough University (© The Author(s)). The authors of this paper acknowledge the right of Loughborough University to publish the paper under the Creative Commons Attribution 4.0 International (CC BY-NC 4.0) licence.

DOI: https://doi.org/ 10.17028/rd.lboro.9741278

created a unique, flexible product that could be incorporated into knitted and woven textiles. Experimentation had led to development of several prototype E-textiles [4–6]. A semi-automated production line was created in 2017, in order to increase the speed of E-yarn production, which was initially hand crafted [7]. This meant that E-yarn could be produced in sufficient quantities (of the order of tens of semiconductor dies within E-yarn per day), to enable use in projects requiring numerous dies within E-yarns.

E-yarn was originally designed with the intention that it could be processed in knitting and weaving machinery, with standard textile yarns, in automated production processes. The Light my Elbows Cycling Jacket project was devised to investigate the feasibility of creating woven cloth containing E-yarn, using a TC2 digital jacquard loom (Tronrud Engineering, Hønefoss, Norway). The development of the jacket, discussed here, represents an innovative prototype garment that brings together fashion and functionality whilst showcasing the potential of E-yarn.

1.1 LEDs (Light-Emitting Diodes) within E-Yarn

LED-yarns, which are E-yarns containing LEDs (light-emitting diodes), were chosen for this project, as they are visible when illuminated, making it straightforward to highlight their presence within E-textiles. The intention of the project team was to find out how the design of garments containing E-yarns could be developed, so that other types of E-yarn [8,9] could subsequently be incorporated into textiles using looms, knitting and embroidery machinery. To clarify the terms used here: E-yarn is a generic term that includes yarns with only a conductive core, as well as yarns containing sensors or LEDs. LED-yarn refers to E-yarn containing LEDs linked by conductive wire. In recent prototype developments, LED-yarn was successfully embroidered onto the surface of a dress [10], and onto stretch fabric for use in a carnival costume [11]. In an earlier project in 2012, E-yarns were hand woven into a single-colour, 'composite garment' [12] in the form of a seamless top via a collaboration between Anna Piper, Katherine Townsend and Anura Rathnayake [13,14] (Fig. 2). The acquisition of a TC2 loom and advances in E-yarn made by the Advanced Textiles Research Group presented the conditions for developing a new prototype that involving the strategic placement of LEDs within a textile through use of E-yarn within a more complex woven garment design; plus the incorporation of batteries and circuitry within an E-textile.

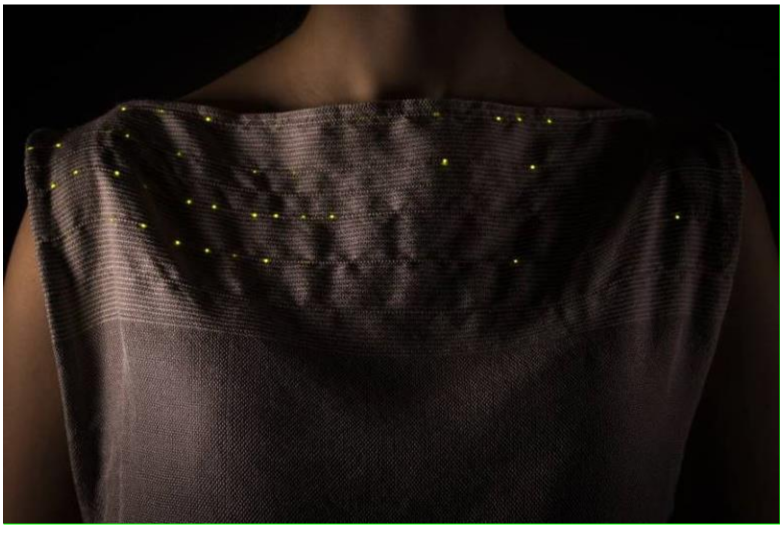

Figure 2: Illuminated Top made in 2012: a composite, seamless garment created by Piper, Rathnayake and Katherine Townsend [13] to test the feasibility of integrating LED-yarns within woven textile products.

1.2 Why a Cycling Jacket?

The Cycling Jacket project, initiated by the authors and a wider team in October 2018, provided an opportunity to show how LED-yarns could be incorporated into clothing without affecting the drape and feel (hand) of a textile within a specific garment structure. The illumination derived from integrating LED-yarns could be put to practical advantage in a garment in which the E-yarn functionality would be beneficial.

Cycle clothing with increased visibility can be divided into:

1. High visibility garments where visibility is created through fluorescent colour and retroreflective elements [15].
2. Illuminated wear, which includes garments with integrated LEDs [16,17]
3. Interactive garments such as the Lumo X Ford: Smart Jacket [18] that illuminates an indicator light when an arm is raised to signal that a cyclist is turning left or right.

Most cycling jackets have been developed via the sportswear or safety markets, and carry the design conventions of those markets. The design and construction of cycling jackets generally involve a combination of: suitable waterproof materials; with the addition of hi-vis, light reflective elements; or, increasingly, ready-made electronic elements needed for lighting functionality. The principle of illuminating clothing, in which lighting is added within, or on the surface, or as accessories, is long established [19,20]. Illuminated cycling jackets are readily available to buy, but few jacket designs were found that also constitute a stylish wearable garment, when not cycling. Contemporary fashion designs incorporating reflective and retroreflective elements include jackets by No Such Thing [21], and Dashing Tweeds' cycling cape [22], in which retroreflective yarns are incorporated into the woven textile. One notable design that does enable interaction but no illumination, is the Levi's® Commuter™ Trucker jacket [23], which provides an interface between a smart phone and a cyclist through the jacket cuff. Conductive thread is woven into the denim fabric of the jacket. This market research revealed a gap in the market and the opportunity to develop a fashionable hi-vis jacket in which LEDs were incorporated into the weave, becoming part of the fabric of the garment.

1.3 Visibility and conspicuousness

The jacket was to be stylish, but also needed to be noticeable when worn by a cyclist, as cyclists are a 'vulnerable [road] user group' [24]. Fluorescent colours on the yellow-orange-red side of the spectrum have been shown to be optimal for this [25]. Use of retroreflective materials was also considered, as these are useful in aiding visibility in low lighting and after dark [26]. Cyclists can be made more conspicuous to other road users through use of dynamic visibility aids [27]. Placing visibility aids on areas that highlight biological motion, such as movement of a cyclist's joints, has been shown to increase conspicuousness [28]. This could be achieved through introduction of flashing light on moving parts of the cyclist's body, such as the elbows. Illumination of the jacket elbows therefore became the focus of this project.

1.4 Aims of the Research

The aims of the research were to design and make a multifunctional jacket with illuminated elbows, suitable for cycling on a bicycle with dropped handlebars, at the same time as being appropriate for everyday wear in other situations such as work or leisure. This included creation of a bespoke textile fabric with LED-yarns placed accurately within the weave; requiring the development of methods to integrate and connect E-yarns within a practical garment. Design for disassembly: for recycling and disposal, was to be investigated throughout the project [29].

2 METHODOLOGY

The Light my Elbows Cycling Jacket was developed by adopting a creative, experimental, practice based research approach, which built on previous collaborative E-textile projects [30], and the process of reflection in action [31]. The woven jacket was designed and made by a team (the authors) that included experts in pattern cutting, embroidery, circuit design, garment design, and electronic textiles. Several members of the team were cyclists, and interaction with cyclists was important in this project, aiding a user-centred design approach [32,33]. The novel aspects of the jacket design are given here, highlighting the interactions between the different members of the design team.

2.1 Power

Electrical power was required to illuminate the LED-yarns that were to be incorporated into the weave. Generation of electrical power on the jacket was discussed. Use of solar power (photovoltaic cells) was not feasible, as the jacket was designed for use in low light or darkness. Generation of energy from body heat or movement was also not feasible, as literature shows that these cannot yet provide a sustained level of power at a level required for LED lighting [34,35]. Another option would have been to attach the jacket circuitry to a power generation device such as a dynamo that was attached to the wearer's bicycle. The power issue was considered to be a project within its own right, with very different requirements from the need to show how LED-yarns could be incorporated into a wearable jacket, so was not taken forward. Battery power was therefore the chosen solution, using rechargeable batteries that could easily be removed from the jacket for charging, assisting in the aim of designing for disposal. Positioning of the batteries within the garment then became a feature of the tailoring.

2.2 Tailoring the design to the body

The garment making process started by designing a (safety) jacket for a cyclist that could also be suitable to wear during other activities. The design was based on a cycling jacket being developed by Eloise Salter for her MA studies focused on creating stylish but safe women's cycle wear (Fig. 3). The jacket was designed with clean lines: to be smart, practical and to work with the body of the cyclist in action. The use of woven fabric, with its ability to retain shape, meant that tailoring to the form was required, rather than relying on stretch. The jacket was specifically designed to accommodate a cyclist bending over a bicycle with dropped handlebars, by creating shaping the sleeves to naturally accommodate their positioning: held forward, in front of the torso. This was developed by wrapping fabric around the arm of a cyclist bent over dropped handlebars. Iterations of the design enabled the development of a sleeve that did not pinch or ride up the arms, through a combination of draping of the form and pattern cutting resulting drapes. The resulting sleeve had a seam that twisted around the arm. Interactions between the pattern cutters and circuitry designers were then required, so that LED-yarns could be accommodated within the elbow, with connections made to batteries. Batteries and circuit boards were attached to double pockets within the side seams, using Velcro®.

Figure 3: An initial jacket design with twisted sleeve seams, designed to be comfortable when leaning over bicycle dropped handlebars.

2.3 LED-yarn within weave

The first stage in this interdisciplinary work was to design LED-yarns that could be incorporated into the jacket sleeves. The aim was to keep the light emitting functionality close to the elbows, so the jacket sleeves were designed to incorporate LED-yarns within a woven structure, worked with the proposed style of the garment. Visibility of the LEDs was important to the design, so bright white LEDs (3.2 V White LED 1005 (0402) SMD, Panasonic LNJ047X8ARA; RS Components Ltd., Corby, UK) were incorporated within LED-yarn [7]. LED-yarns were made specifically for this project. The required spacing between LEDs in each LED-yarn had to be decided before manufacture. This decision required considerable interaction between team members to calculate the exact positioning of LEDs within weave for use in sleeves still at the design stage. This was accomplished by using plain E-yarns (without LEDs) to create weave samples, at the same time as finalising the jacket design, which progressed each part of the design to the stage where optimal LED positioning could be ascertained (see section 2.3.2).

2.3.1 Weave design. Test warps were developed on the TC2 loom to accommodate the 2mm diameter LED-yarn. The chosen design was a simple geometric block pattern, using dark grey (PG812) yarn on the warp, with weft in the same dark grey, plus fluorescent orange (PGCD050) 1/167 dtex, dyed, textured multifilament polyester yarn (Ashworth and Sons, Cheshire, UK), plus retroreflective yarn. The LED-yarns were sandwiched within a double cloth construction that supported them within the fabric, preventing damage. The ends of the LED-yarns had to emerge from the weave at strategic points, to be connected to create a circuit. The points at which the ends of each LED-yarn emerged from the weave were selected in consultation with the pattern cutters and circuitry designers, so that sufficient space was provided on the cloth to form embroidered connections between LED-yarns, whilst minimising exposed lengths of LED-yarn outside the weave.

2.3.2 Positioning the LEDs within the sleeves was a challenge that needed input from all the members of the team. The LED-yarns were inserted on the weft, so ran through the straight-of-grain of the weave, but the weave was to be used on the bias, creating the required twisted sleeve that would accommodate the outstretched arms of the cyclist. This manipulation meant that the LED-yarns ran diagonally over the elbows. Fig. 4 shows the method used to mark the LED positions around the elbow area on a toile. The challenge for the weaver was then to place the LEDs within each LED-yarn into the bespoke weave at these positions.

2.3.4 Removal of LED-yarns from the weave was relatively easy, in order to separate electronics from the jacket. The electrical core of the LED-yarns could then be extracted from the textile sheath. This provided a method of extracting the small (0.5 x 1.0 x 0.2 mm) LEDs and thin copper wire from the jacket, despite the high level of integration of the LEDs into the textile structure. Replacement of one LED-yarn was undertaken after failure of the LEDs. This was a time-consuming, skilled process.

Figure 4: LED positions marked on the toile sleeve using masking tape.

2.4 Embroidered electrical connections

Ends of LED-yarns protruding from the woven cloth required connection to form an electrical circuit. Previous work on connection of E-yarns [11] had involved soldering together of the multi-strand copper wire (7-strand copper wire with 50 µm strand diameter: Knight Wire, Potters Bar, UK) that formed the core of E-yarns. This created fragile, brittle junctions which were then covered in UV-curable resin to add strength. Both soldering and resin addition were difficult to carry out on E-yarns protruding from cloth, and could lead to damage to the weave. This use of electronics techniques on a textile required improvement. A textile-based method of creating junctions was preferred. Embroidery was chosen, as this could maintain flexibility of the textile sleeve, and there was precedent for this [36]. A new method was required in order to work with E-yarn, in which conductive copper wire was contained within a textile sleeve. This flexible copper could be threaded through needles and used to make loops and stitches. A stitch ripper was used to sever the outer, braided sleeve of each LED-yarn, so that a length of copper wire could be exposed. A 5 mm copper jump ring (19 Gauge, GC/JR036X5; Beadaholique, Glendale, California, USA) provided a stable, conductive point around which copper wire was wrapped (Fig. 5). Use of the copper ring made it feasible to connect several E-yarns at one point, by looping each copper wire around the ring several times.

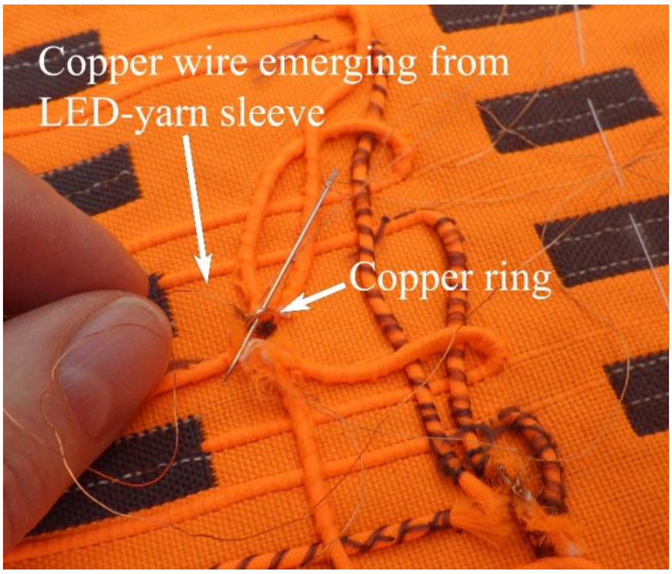

Figure 5: A stage in the use of a copper ring to form of a connection between E-yarns. The needle is threaded with copper wire that emerges from an LED-yarn sleeve.

The embroidery method produced exposed electrical junctions which required covering to prevent short circuiting which could have happened if one copper ring came into contact with another as the sleeve was flexed. Small patches were made to cover each junction (Fig. 6). These had a conductive side made from copper polyester taffeta fabric (Less EMF Inc, Latham, New York, USA) and a piece of the charcoal cloth used to make the jacket body (Ventile L24 waterproof, breathable cotton; Point North, Chester, UK) to provide electrical insulation on the side that would be in contact with the wearer. There was concern that the thin copper wire that had been used to make the electrical connections would fray during flexing of the sleeve. It was hoped that the copper patch could assist in maintaining conductivity of the junction if this started to occur. The conductive surface area of the patch was therefore increased by covering the conductive textile with loops of embroidery made from copper wire (Knight wire, as used in the LED-yarns) using a Cornely embroidery machine (114W103, Singer Sewing Company, La Vergne, Tennessee, USA).

Figure 6: A conductive patch with insulated backing. The surface of the copper fabric has been covered with looped embroidery.

2.6.1 The junctions between LED-yarns were compatible with the aim of design for disassembly. Threading the copper wire through a copper hoop, instead of embroidering copper into the textile, ensured that the copper components could be separated from the textile by unpicking the conductive patch, then pulling off the copper hoop. This left ends of copper wire protruding from the E-yarns. Removing the E-yarns from the weave would remove all further copper from the textile.

2.5 Batteries and additional circuitry

Batteries and control circuitry were required within the jacket, to power and control the LED-yarns (Fig. 7). LED-yarns emerging from the weave were connected to E-yarns that were run through seams to provide electrical connection to the circuit board and batteries that were attached to the insides of the jacket pockets.

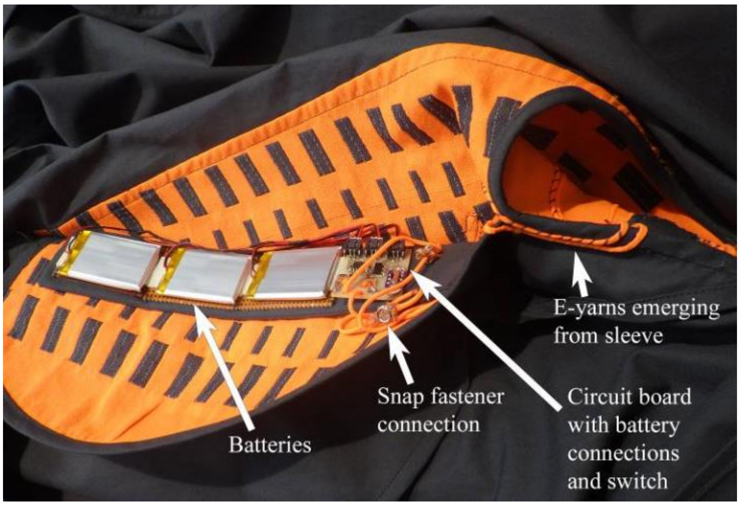

Figure 7: Batteries and circuit board attached to a double pocket

The batteries and circuit board could have been included within the sleeve, as close to the LED-yarns as possible, but it was felt that this would have made the jacket uncomfortable and would have caused the loose-fitting sleeves to sag. Instead, the batteries were placed on the side seams of the body of the jacket. The weight and bulk of these extra components was minimised through use of light and thin components. Lithium polymer batteries (TruPower L350 Lithium Polymer Battery 3.7V 350mAh; Rapid Electronics Ltd., Colchester, Essex) were selected to power the LED-yarns, due to their high energy density and availability in a thin, flat form (48 x 35 x 3 mm) that would not create bulges when placed within the jacket. A picaxe controller was used to control the flashing LEDs (PICAXE AXE007M2-SM-08M2 IC (150mil SOIC); Rapid Electronics Limited, Colchester, UK), due to its small size and low power consumption. This was included on a small circuit board that also incorporated sockets for the battery connections and a switch. The LEDs in each sleeve were activated by switches on the circuit boards, which could easily be reached inside each side of the jacket. E-yarns emerging from the jacket sleeve were attached to the board using snap fasteners. This made removal of these electronic components straightforward for battery charging, for garment washing, or when the lighting was not required.

3 RESULTS AND DISCUSSION

The Cycling Jacket (Fig. 8) was completed in May 2019, after 7 months of collaborative work. Developing an aesthetic, functional jacket design had led to an iterative process, with members of the team working individually and together to work-out solutions to each tailoring, weaving, construction or connection challenge as it arose, to accommodate the electronics whilst maintaining a stylish and practical outcome. After numerous meetings and discussions, pattern cutting and weaving adjustments, experimental toiles and embroidered connections, the electronics were integrated inconspicuously into the resulting jacket with flashing LEDs visible on the jacket's elbows. The jacket's sleeves conformed to and moved with a cyclist's arms without any noticeable difference caused by the LED-yarns within the weave.

Figure 8: The completed jacket with LEDs visible in the elbows

The collaborative process of designing and making of the jacket demonstrated the need for multifaceted interactions between those creating a practical piece of tailoring and the requirements created by the insertion of electronics into the structure. One example of this was the collaboration required to adjust the design of the twisted sleeve, so that LED-yarns would emerge at a point on the arm where they could run into the jacket side seams. This point was placed so that a cyclist wearing a rucksack would not lead to the rucksack straps chafing against the LED-yarns.

The LED-yarns themselves were a successful fusion of electronics and textiles, creating a flexible structure for incorporation into a textile. This jacket design project provided a platform for experimentation to find ways of integrating every aspect of the electronic circuitry into a functional textile garment. The jacket was designed for exhibition, display in a lab, and for photoshoots, to test and demonstrate how E-yarns can be integrated into woven products. Design for disassembly was addressed, with the batteries and circuit board being easy to remove. Further developments could shrink the size of this circuitry and have this inserted into a waterproof box or bag that would protect the components from rain and sweat. The LED-yarns could be replaced if breakage occurred, but further developments in the weave design would be required to make this a straightforward process. The embroidery used to create electrical connections was kept separate from the textile, so that all the copper wire and cloth could easily be separated from the textile by removing the copper fabric that covered each connection. Further work could include design of bespoke connectors for E-yarns. Ideally, these would themselves be straightforward to disassemble, enabling complete separation of textiles from other materials. The number of connections and amount of peripheral circuitry could be further reduced by including more circuitry within E-yarns, including circuitry on flexible polyimide strips [9]. Further iterations of the jacket could include functionality such as photodiode yarns [6] to enable automatic illumination of the LEDs in low light. The testing of further iterations of the design is expected to lead to future design developments, such as confirmation and enhancement of the visibility of the illuminated jacket elbows in different user and weather conditions.

ACKNOWLEDGMENTS

The authors acknowledge funding from EPSRC grant EP/M015149/1: Novel manufacturing methods for functional electronic textiles.

The authors would like to thank Ioannis Anastasopoulos, Theodore Hughes-Riley, Mohamad Nour Nashed, Carlos Oliveira and Arash Shahidi (of the Advanced Textiles Research Group, Nottingham Trent University), for technical assistance, especially in the fabrication of E-yarns.

REFERENCES

[1] Tilak Kithsiri Dias and Anura Rathnayake. 2018. Electronically Functional Yarns. Retrieved from https://worldwide.espacenet.com/searchResults?search=EP3191632B1&DB=EPODOC&submitted=true&locale=en_EP&ST=singleline&compact=false&DB=EPODOC&query=EP3191632B1
[2] Statex. 2019. Shieldex® Yarns. Retrieved 3 June 2019 from https://www.statex.de/en/shieldex-yarns/
[3] Scientific Wire Company. 2019. Textile Covered Copper Wire. Retrieved 3 June 2019 from https://www.scientificwire.com/acatalog/textile-cu-wire.html
[4] Pasindu Lugoda, Theodore Hughes-Riley, Carlos Oliveira, Rob Morris, and Tilak Dias. 2018. Developing Novel Temperature Sensing Garments for Health Monitoring Applications. Fibers 6, 3 (July 2018), 46. DOI:https://doi.org/10.3390/fib6030046
[5] Theodore Hughes-Riley and Tilak Dias. 2018. Developing an Acoustic Sensing Yarn for Health Surveillance in a Military Setting. Sensors 18, 5 (May 2018), 1590. DOI:https://doi.org/10.3390/s18051590
[6] Achala Satharasinghe, Theodore Hughes-Riley, and Tilak Dias. 2018. Photodiodes embedded within electronic textiles. Sci. Rep. 8, 1 (December 2018), 16205. DOI:https://doi.org/10.1038/s41598-018-34483-8
[7] Dorothy Anne Hardy, Ioannis Anastasopoulos, Mohamad-Nour Nashed, Carlos Oliveira, Theodore Hughes-Riley, Abiodun Komolafe, John Tudor, Russel Torah, Steve Beeby, and Tilak Dias. 2019. Automated insertion of package dies onto wire and into a textile yarn sheath. Microsyst. Technol. (March 2019), 1–13. DOI:https://doi.org/10.1007/s00542-019-04361-y
[8] Pasindu Lugoda, Theodore Hughes-Riley, Rob Morris, and Tilak Dias. 2018. A Wearable Textile Thermograph. Sensors 18, 7 (July 2018), 2369. DOI:https://doi.org/10.3390/s18072369
[9] Menglong Li, John Tudor, Russel Torah, and Steve Beeby. 2018. Stress Analysis and Optimization of a Flip Chip on Flex Electronic Packaging Method for Functional Electronic Textiles. IEEE Trans. Components, Packag. Manuf. Technol. 8, 2 (February 2018), 186–194. DOI:https://doi.org/10.1109/TCPMT.2017.2780626
[10] Bonnie Binary. 2018. Red Dress featuring illuminated Electronic Yarn – Bonnie Binary. Retrieved 20 March 2018 from http://www.bonniebinary.co.uk/portfolio/red-dress/
[11] Dorothy Hardy, Andrea Moneta, Viktorija Sakalyte, Lauren Connolly, Arash Shahidi, and Theodore Hughes-Riley. 2018. Engineering a Costume for Performance Using Illuminated LED-Yarns. Fibers 6, 2 (June 2018), 35. DOI:https://doi.org/10.3390/fib6020035
[12] Anna Piper and Katherine Townsend. 2015. Crafting the Composite Garment: The role of hand weaving in digital creation. J. Text. Des. Res. Pract. 3, 1–2 (July 2015), 3–26. DOI:https://doi.org/10.1080/20511787.2015.1127037
[13] Colin Cork, Tilak Dias, Tessa Acti, Anura Ratnayaka, Ekael Mbise, Ioannis Anastasopoulos, and Anna Piper. 2013. The next generation of electronic textiles. In Proceedings of the 1st International Conference on Digital Technologies for the Textile Industries. Manchester. Retrieved from http://www.texeng.net/conferences/first-international-conference-on-digital-technologies-for-the-textile-industries.html
[14] All-Party Parliamentary Design and Innovation Group. 2012. Future Textiles Exhibition. Retrieved 14 June 2019 from https://www.policyconnect.org.uk/apdig/apdig/events/future-textiles-exhibition
[15] Health and Safety Executive. High visibility clothing. Retrieved 6 June 2019 from http://www.hse.gov.uk/workplacetransport/factsheets/clothing.htm
[16] Gear. 2017. Performance LED clothing: Métier's illuminating jackets - Journal. Rouleur. Retrieved 6 June 2019 from https://rouleur.cc/editorial/performance-led-metier-clothing/
[17] NEW: Nightrider LED Men's Cycling Jacket | Proviz. Retrieved 6 June 2019 from https://www.provizsports.com/en-gb/nightrider-led-mens-cycling-jacket.html
[18] Lumo. 2019. LUMO X Ford: Smart Jacket. Retrieved 5 June 2019 from https://www.lumo.cc/blog/lumo-x-ford-smart-jacket
[19] Theodore Hughes-Riley, Tilak Dias, and Colin Cork. 2018. A Historical Review of the Development of Electronic Textiles. Fibers 6, 2 (May 2018), 34. DOI:https://doi.org/10.3390/fib6020034
[20] 1884. The Electric Diadems of the New Ballet 'La Farandole'. Sci. Am. 50, 11 (1884). Retrieved 4 August 2017 from https://www.scientificamerican.com/magazine/sa/1884/03-15/
[21] No Such Thing. Stand out in the street. Retrieved 5 June 2019 from http://www.nosuchthing.clothing/
[22] Dashing Tweeds. Reflective Ladies Cape. Retrieved 6 June 2019 from https://www.dashingtweeds.co.uk/product/ladies-cape/
[23] Google. 2017. Jacquard by Google. atap.google.com. Retrieved 29 September 2018 from https://atap.google.com/jacquard/
[24] Mike Dark. 2018. Pedal Cycling Road Safety Factsheet. Retrieved 6 June 2019 from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/686969/pedal-cycle-factsheet-2017.pdf

[25] I Kwan, J Mapstone, and I Roberts. 2002. Interventions for increasing pedestrian and cyclist visibility for the prevention of death and injuries. In The Cochrane Database of Systematic Reviews, Irene Kwan (ed.). John Wiley & Sons, Ltd, Chichester, UK, CD003438. DOI:https://doi.org/10.1002/14651858.CD003438

[26] Helen S. Koo and Xiao Huang. 2015. Visibility aid cycling clothing: flashing light-emitting diode (FLED) configurations. Int. J. Cloth. Sci. Technol. 27, 3 (June 2015), 460–471. DOI:https://doi.org/10.1108/IJCST-09-2014-0104

[27] S Fotios and HF Castleton. 2017. Lighting for cycling in the UK—A review. Light. Res. Technol. 49, 3 (May 2017), 381–395. DOI:https://doi.org/10.1177/1477153515609391

[28] Joanne M. Wood, Richard A. Tyrrell, Ralph Marszalek, Philippe Lacherez, Trent Carberry, and Byoung Sun Chu. 2012. Using reflective clothing to enhance the conspicuity of bicyclists at night. Accid. Anal. Prev. 45, (March 2012), 726–730. DOI:https://doi.org/10.1016/J.AAP.2011.09.038

[29] A. McLaren, D.A. Hardy, and T. Hughes-Riley. 2017. Electronic textiles and product lifetimes: exploring design strategies for product longevity. In PLATE: Product Lifetimes And The Environment, C.A. Bakker and R Mugge (eds.). IOS Press, Delft.

[30] Sarah Kettley, Katherine Townsend, Sarah Walker, and Martha Glazzard. 2017. Electric Corset: an approach to wearables innovation. RTD 2017 Proc. 3rd Bienn. Res. Through Des. Conf. (2017), 486–500. DOI:https://doi.org/http://doi.org/10.6084/m9.figshare.4747027.v1

[31] Jean Mcniff. 2017. Action Research All You Need to Know. Sage, London. Retrieved 14 June 2019 from https://uk.sagepub.com/sites/default/files/upm-binaries/81701_McNiff_Action_Research.pdf

[32] Oya Demirbilek and Bahar Sener. 2003. Product design, semantics and emotional response. Ergonomics 46, 13–14 (October 2003), 1346–1360. DOI:https://doi.org/10.1080/00140130310001610874

[33] Marc Hassenzahl. 2004. The Interplay of Beauty, Goodness, and Usability in Interactive Products. Human-Computer Interact. 19, 4 (December 2004), 319–349. DOI:https://doi.org/10.1207/s15327051hci1904_2

[34] M Geisler, S Boisseau, M Perez, P Gasnier, J Willemin, I Ait-Ali, and S Perraud. 2017. Human-motion energy harvester for autonomous body area sensors. Smart Mater. Struct. 26, 3 (March 2017), 035028. DOI:https://doi.org/10.1088/1361-665X/aa548a

[35] Zhisong Lu, Huihui Zhang, Cuiping Mao, and Chang Ming Li. 2016. Silk fabric-based wearable thermoelectric generator for energy harvesting from the human body. Appl. Energy 164, (February 2016), 57–63. DOI:https://doi.org/10.1016/J.APENERGY.2015.11.038

[36] Leah. Buechley, Kylie A. Peppler, Michael Eisenberg, and Yasmin B. Kafai. 2013. Textile messages: dispatches from the world of e-textiles and education. Peter Lang Publishing Inc.