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Using Smart Fabrics to Automate Bio-Monitoring Show-Jumping Horses for Training Improvements

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1 Intro to Research Area

Wearable technology has been around for the past decade. There has been a constant need to make things fashionable for wearers for easy incorporation of technology into their daily life – without having to change their routine – and enhancement. In the past couple of years, this idea has become more actualisable with an advancement in e-textile research (Seymour, 2012; Tao, 2015; Zhang & Tao, 2001). Also known as smart fabrics, e-textiles are textile substrate that incorporates capabilities for sensing (biometric or external), communication (usually wireless), power transmission, and interconnection technology to allow sensors or things such as information processing devices to be networked together within a fabric (Berzowska, 2006). In this report, both terms will be used interchangeably. Given the current state of the art with detection of health states in humans, this project was undertaken to assess how feasible using smart fabrics in the detection of health states in animals could be. Performance show-jumping horses were used as a case study.

Through reviewing the literature, it was found that smart fabric sensors are built on base materials – such as conductive yarn (Cork, 2015), textile electrodes (Muhlsteff & Such, 2005) and conductive polymer (Li et al., 2005) – that when either integrated together or on their own, could be used as a part of a working textile circuit to receive and transmit necessary information. With horses, it has been noted that their temperature, respiration and heart rate need to be monitored contiguously during its different physical state, through resting to exercising to cooling down (Pilliner, 1994). The data should be logged in real-time instead of being batch collected to help establish a better normal range. Smart fabrics have been geared towards bio-monitoring in humans. There appear to be several possibilities for adapting for bio-monitoring horses, as they could perform the same tasks, but on a much larger scale.

In Section 2, more background context about show-jumping horses and what health states are important for bio-monitoring to help improve training will be first discussed. Methods of research and method findings will also be discussed later in the section. In Section 3, the base materials used to create smart fabric sensors will be looked at further in more depth, and relevant past projects with smart fabrics will be looked at after to help better visualise the concept of how base materials and fabric sensors could look and work when fully integrated. After having looked at every smart fabric base material, in Section 4, the opportunities to integrate and adapt smart fabric sensors into riding gear to bio-monitor horses based on method findings will be discussed. Each possible match will be assessed based on feasibility and advantages. In Section 5, the final conclusion on what sensors and materials could be best for adaption will be discussed and future directions will be looked at.

2 Background Contexts

In the following section, more context will be given to what show-jumping as a sport entails for mainly the horse, and briefly the rider. The conditions for determining fitness within the horse will be assessed and reasons why smart fabrics should be used will be given. The direction taken in approaching finding publications and brief findings will also be discussed, highlighting keywords, journals and books that were found to be relevant to this project.

2.1 Show Jumping and Conditioning

Show jumping is a "competitive equestrian event in which horse and rider are required to jump, usually within a time limit, a series of obstacles that have been designed for a particular show" ("Show Jumping," 1999). Training regimens differ between performance horses, but all vital health states for monitoring remain the same.

For a horse to be considered fit, they have to be correctly worked and properly fed. Feeding is dependent on nutritional needs the horse is lacking, but the working the horse depends the jumper putting in the right amount of effort into maintaining the horses fitness through training, without overworking the horse. There are three major health states to look out for when assessing the fitness of a horse. They are temperature, heart rate and respiration. The changes in these health states as direct consequences of the current physical state of the horse (Pilliner, 1994) have been complied into Table 1.

	Temperature	**Heart Rate**	**Respiration**
Resting	This is usually at 38º, but in shock it will drop, and in a fever it will rise.	This can be between 36 – 42 beats per minute.	This can be around 36 – 42 breathes per minute.
Exercising/Active	For an event horse, it is normal for their temperature to rise up to 40ºC*.	This can rise up to 240 beats per minute. As the horse gets fitter, there is a less dramatic increase.	This can go up to 120 breathes per minute. As the horse gets fitter, there is a less dramatic increase.
Cooling Down	The temperature is maintained within a narrow range by the body.	The fitter the horse, the slower the resting heart rate.	The fitter the horse, the quicker the recovery rate.

** This is just rectal temperature. Core temperature – the horse's ability to store some heat – will be 2º higher.*

Table 1 - Table showing how physical states affect health states. Source: Pilliner, 1994.

Different performance horses have different fitness needs. Show jumping is a specialist sport, and much of the fitness programme consists of schooling the horse and improving its jumping technique so its training and fitness go together (Pilliner, 1994). A Temperature-Heart Rate-Respiration (THR) normal range is found by comparing results when calm and at rest to results when exercising (Pilliner, 1994).

Riders feel a pressure for immediate success from the owners, without the necessary groundwork and time essential for the development of effective horse-rider partnerships (Dashper, 2014). Equestrian coaches often emphasize the importance of feel but have no objective means of assessing it (Damien et al., 2014). The introduction of smart fabrics into biomonitoring of these horses could help reduce the time spent collecting and interpreting this data and allow more time for the rider to build up a better horse-rider relationship.

2.2 Method

A literature review was conducted, focused on two specific topic areas: e-textiles and horse health states. Journals where first searched, then books.

With e-textiles, the initial keywords used in searches that yielded the most relevant results for this study were: e-textiles, electronic textiles, smart fabrics and interactive textiles (SFIT), smart textiles, wearable systems, digital textiles. New unique keywords that arose during these searches were: communication, microsystems, conductive yarns, heat regulating textiles, information, product innovation, wearable technology, degree of technology integration and responsive textile structures. These keywords yielded results in the following publications:

- Journals
    - The International Journal of Clothing Science and Technology
    - Inventions
    - Sensors (Switzerland)
    - Synthetic Metals
    - Textile Asia
    - IBM Systems Journal
    - Nature Nanotechnology
    - TEXTILE
    - IEE Sensors Journal
    - MRS Bulletin
- Conference Proceedings
    - 2008 30th Annual International Conference of the IEEE Engineering in Medicine and Biology Society.
    - 2005 26th Annual International Conference of the IEEE Engineering in Medicine and Biology Society
    - Nanosensors, Biosensors, and Info-Tech Sensors and Systems
- Books
    - Handbook of Smart Textiles
    - Electronic Textiles: Smart Fabrics and Wearable Technology
    - Designing with Smart Textiles

Regarding show-jumping horses, the research focused on their health states and how their fitness affects their training. With this narrowed focus, the initial key words used were equestrian sport, show-jumping, competitive horse, horse training, performance horse. With this first basic search, some interesting keywords popped up. They included equitation science, horse-human relationships, commercialization. These keywords yielded results in the following publications:

- Journals
    - Journal of Veterinary Behavior: Clinical Applications and Research
    - Applied Animal Behaviour Science Journal
    - Society and Animals
- Books
    - Getting Horses Fit

Journals were found through Google Scholar and Mendeley, while books were found through TUG Primo, through the University of Guelph.

3 Method Findings

While searching for publications to review, it was found that there was a big time gap in the literature about smart fabrics. There was a spike in relevant work between 2000 and 2006, when the technology was still new and emerging. Most of the literature discussed future directions based on hopes of technological advancements. Few relevant publications were found until around 2012, where it picks up again. It seems that the aforementioned technological advancement and the hope for its utility and application, and its feasibility did not immediately materialize, but interest in these technologies seems to be picking up again.

3.1 E-Textiles and Humans

Smart fabrics use various sensors to accomplish desired tasks. There are three categories:

1. Passive smart – sensors only, which act in a predetermined way, with no influence from environmental factors.
2. Active smart – include an actuator function, i.e. react to environmental factors.
3. Very smart – not only do they react to environmental; they adapt to them.

(Kettley, 2016).

Smart fabrics offer natural interfaces with the body based on accurate and positioning of the sensors. Sensors can be enclosed within the layers of the fabric, or is the fabric itself as sensor or distributed network of sensors (Lymberis & Paradiso, 2008).

Big fashion corporations have taken an active role in redesigning with smart fabrics, allowing people to not have to relearn how to use their products, while enjoying the added benefits. A good example of this is the Nike Adapt BB basketball shoe Figure 1, part of the Nike+ range. They created an 'advanced power-lacing system' which uses a motor to sense tension and adjust the snugness of the shoe to the foot. Another example is the Adidas-Textronics miCoach Seamless Smart Bra, which uses biomechanical sensors made from knitted conductive fibres to measure respiration rate, heart rate and calories of the wearer and contiguously logged this personalised data into an app for easy reading (Adidas, 2015).

Figure 1 – Nike[R] Adapt BB Basketball Shoe. Source: https://news.nike.com/news/nike-adapt-bb

Figure 2 – Adidas[R] miCoach Seamless Smart Bra. Source: https://ideaing.com/product/adidas-micoach-seamless-heart-rate-monitoring-smart-bra

Smart fabrics have generally been tested and geared towards human subjects. They have been mostly used in biomonitoring and protection. Fabric sensors can be used for electrocardiogram (ECG), electromyography (EMG), and electroencephalography (EEG) sensing (Stoppa & Chiolerio, 2014).

In construction, most smart fabrics have embedded capacitive, resistive, and optical sensors. This allows the textile to sense touch, strain, pressure, temperature, and humidity. The sensors are just a small part of a big system. They are normally connected to control boards, which process the information (Gonçalves, Ferreira da Silva, Gomes, & Simoes, 2018).

Smart fabrics consist of different types of fabric sensors to fulfill different purposes. Base materials can either be used in conjunction with each other or as standalones in creating these fabric sensors. The categories of sensors include:

- Bio-Sensors – sensors used for monitoring of health states.
- Conductors – materials used for data transmission.
- Strain Sensors – sensors used to detect and measure strain and displacement.
- Thermal Sensors – sensors that can sense temperature changes.
- Optical Sensors – sensors that detect changes in light.
- Pressure Sensors – sensors used to detect changes in pressure.
- Actuators – sensors used to convert the smart fabric from passive smart to active smart.

There are common base materials used in different quantities and pairings to create any of the sensor types listed above. There is no restriction on what base material can be used to create a desired sensor. However, there are some benefits of using one material over another. Each material, their advantages and disadvantages are discussed below.

3.2 Fabric Sensor Base Materials

As mentioned in Section 3.1, fabric sensors fall under different categories, dependent on the intended use. These sensors are actualised using different base materials, either alone or mixed with another base material. In the following subsections, each major base material will be further discussed, with its advantages and disadvantages. They are arranged alphabetically.

3.2.1 Carbon Nanotubes (CNT)

CNTs are conductive additives to be mixed with conductive polymers for use (Qu & Skorobogatiy, 2015a). CNTs are soldered onto the fiber surface of a non-woven fabric by either ultrasonication or melt spinning (Miao, 2015), which brings a strong adhesion between the carbon nanotubes and the textile fibers. CNTs do not detach under vigorous movement or after being washed (Gonçalves et al., 2018). Even though they are currently very expensive to produce, with an estimate being around $50/g (NASA, n.d.), they hold a good amount of promise (Cork, 2015). CNT yarns consistently achieve higher tenacity than many traditional textile yarns possess a high resistance to abrasion and knotting (Miao, 2015). They also have a high-aspect ratio, are lightweight and possess good electrical and thermal properties (Gil Min, Gi Chae, Minus, & Kumar, 2009; Qu & Skorobogatiy, 2015a). There are also research projects reporting the use of nanosoldering methods to produce e-textiles with carbon nanotubes (CNT) conductive lines, but not enough to assess the feasibility of this method (Qu & Skorobogatiy, 2015b).

3.2.2 Conductive Yarn

Conductive yarn seems to be the simplest solution to introducing mechanical properties to plain textile substrates. The development of flexible conductive yarns with diameters that are similar to the conventional textile yarns enable the use of traditional fabrication methods to merge conductive threads with non-conductive threads. Coating non-conductive yarns with metals, galvanic substances or metallic salts can also be used to make electrical conductive yarns from pure textile threads, which also enables an e-textile production. (Gonçalves et al., 2018). Even though damage to conductive yarn could lead to a loss of electronic functionality, the large surface area and number of fibres offers the opportunity of fault tolerance (Cork, 2015). Most conductive yarn is metal-based, with popular favour being given to sliver yarns. Metal-based yarns have their strength and composition and are readily available in textile form at low costs. Even though it is cost effective and a good conductor, metal wires have low elasticity and strength and can break, or even corrode over time, due to wear and washing. Also, due to its inertness it is not sensitive to washing or sweating. They cannot provide uniform heating and are heavier than most textile fibers making homogeneous blends difficult to produce (Cork, 2015; Stoppa & Chiolerio, 2014). Conductive yarn seems to the base material on which most the other materials seems to build upon. Conductive yarn is the main material used in making piezoresistive and piezoelectric sensors, which are used in the creation of strain gauges and respiratory sensors (Gonçalves et al., 2018; Suh, 2015).

3.2.3 Intrinsically Conductive Polymer

Conductive polymer seems to be a better iteration of conductive yarn, as instead of intertwining conductive threads with pure textile threads, the pure textile threads are coated with conductive metal (Gonçalves et al., 2018). This makes it less susceptible to wear and tear. All of the conductive polymers and carbon-based conductive particle polymers have a temperature dependent response (Gonçalves et al., 2018). Conductive polymers are organic materials that are able to transport electricity. There are difficulties to be faced both in the processing of these materials as well as a non-sufficient conductivity for most applications, however in the creation of sensor conductive polymers could be used since these applications are not always dependant on high conductivity (Berglin, 2013).

3.2.4 Optical Fibres

The working principle of optical textile sensors is based on the variation of the light intensity/the amplitude that can be sensed by a Fibre Bragg Grating (FBG) sensor. The optical fiber light source can be a small light emission diode (LED), and the light amplitude at the end of the optical fiber can be sensed with a small photodetector. Because of the FBG property with optical fibres, they can be used to sense deformation (Van Langenhove & Hertleer, 2004). Depending on the textile movements, the light amplitude will change allowing to sense textile displacements and pressures, allowing it to be used where electrical currents cannot cross textile substrates. (Gonçalves et al., 2018). However, drawbacks arise at the interfaces of the optical fibers, as conventional electronics that are required for signal origination and processing and the range of deformation to deal with in textiles is of a different order and causes problems (Post, Orth, Russo, & Gershenfeld, 2010; Van Langenhove & Hertleer, 2004).

3.2.5 Textile Electrodes (Textrodes)

In pioneering e-textile projects like Wealthy and MyHeart, textile electrodes – also known as textrodes – were also used for impedance pneumography i.e. measurement of the voltage changes caused by thoracic impedance change (Lymberis & Paradiso, 2008). Textrode are usually the base sensor used in creating a textile circuit, as they receive information, but cannot transmit this information alone (Gonçalves et al., 2018). Metal-based textrode can be used for ECG and electromyography (EMG) monitoring, which eliminated the need to use electro gel, which caused skin irritation with prolonged exposure and could directly on the skin. But due to irregularities in surfaces and friction from movement, it creates high contact impedance and high frequency noise (Suh, 2015). Since no electro gel is used, optimal contact between the electrode and skin will have to be realised through the structure and composition of the electrode structure itself. Obviously, this contact will improve by putting more pressure on the electrode. A decrease of impedance is observed limiting the influence of noise signals (Van Langenhove & Hertleer, 2004).

A brief summary for each base material and what sensors they can be used to create, along with the best method of installation into textile substrates is given in Table 2.

Base Material	Can be used for…	Can be made into…	Best Method of Installation
Carbon Nanotubes	Conductor, Strain Sensor		Melt Spinning
Conductive Yarn	Conductor, Strain Sensor	Piezoresistive Sensor	Woven / Knitted
Intrinsically Conductive Polymer	Conductor, Strain Sensor, Thermal Sensor		Metal Spinning / Coating
Optical Fibres	Optical Sensor, Bio-Sensor, Thermal Sensor, Actuator	Piezoelectric Sensor	Woven
Textile Electrodes	Bio-Sensor, Conductor	Textile Circuit	Embroidered

Table 2 - Table linking sensor types to the base materials used to make them

3.2 Relevant Past Projects Involving E-Textiles

There are several projects that explore and give further insight to the possible applications that can be achieved with the use of smart fabrics. The most relevant projects in relation to this research have been highlighted in Table 3, with the sensors and base materials used.

Past Projects	Sensors Used	Base Materials Used	Papers Mention In
Wealthy	Thermal Sensor, Strain Sensor, Bio-Sensor	Conductive Yarn, Textrodes	(Berglin, 2013; Lymberis & Paradiso, 2008; Paradiso, Loriga, Taccini, Gemignani, & Ghelarducci, 2005)
myHeart	Thermal Sensor, Strain Sensor	Conductive Yarn, Conductive Polymer	(Berglin, 2013)
Smart Shirt ("Wearable Motherboard")	Strain Sensor, Thermal Sensor, Bio-Sensor	Optical Fibre	(Lymberis & Paradiso, 2008; Park & Jayaraman, 2003)
PROETEX	Thermal Sensor, Bio-Sensor	Textrodes	(Berglin, 2013; "Proetex," n.d.)
Intelligent Knee Sleeve	Strain Sensor	Conductive Polymer	(Li et al., 2005; Suh, 2015)
Film Strain Sensor	Strain Sensor	Carbon Nanotubes	(Suh, 2015; Yamada et al., 2011)
Respibelt	Strain Sensor	Conductive Yarn	(Van Langenhove & Hertleer, 2004)

Table 3 - Table showing relevant past projects and sensors and base materials used

4 Opportunities to Apply E-Textiles to Show Jumping

Smart fabrics designed for athletes and soldiers who go through intense physical training is the most suitable candidates for adapting smart fabrics to the horse show-jumping context. This is due to the fact the horse also undergoes intense physical training, but on a larger scale due to their body mass. There could be possible challenges and factors to take into consideration, such as overall cost, accuracy of obtained signal, low power consumption, interconnection method and unobtrusive design (Kumar, Oh, Kwon, Rai, & Varadan, 2013; Suh, 2015).

These new textiles will be selected to resist wrinkling, because wrinkles compound pressure. The textiles must also be washable and easily demountable, conditions for which smart textiles are likely to excel because they lend themselves to being fitted securely (Damien et al., 2014). The data can now be logged in real-time instead of being batch collected to help establish a better THR normal range, as reading is more accurate and a wider range is given. Each point in THR will be discussed and suggestions for each measurement will be given, depending on feasibility, cost and level of integration.

4.1 Heart Rate

Horses commonly have their heart rate taken from the facial artery under the cheekbone, but also from its left side, just below the elbow (Pilliner, 1994). The bridle usually crosses over sections on the head, with a full one containing a throat latch crossing over this facial artery. With the thin construction of bridles and they need to be properly fitted for that particular horse, the chance for accurate readings increase. A textrode could be the ideal match to monitor this state, as it has the highest feasibility rate. The textile electrodes have then been incorporated into a larger textile garment that can be worn by a horse so there is no need to clip the horse, put clamps on the skin, or use gels to pick up the ECG signal (Damien et al., 2014). In conceptualisation, it could have to be constructed as part of a small textile circuit to replay the data. It could also have to be paired with hydrogel membranes, to reduce the contact impedance and frequency noise experienced by the textrode due to its susceptibility to body motion and improve the signal to noise ratio during body movements (Lymberis & Paradiso, 2008; Suh, 2015) and increase its sensitivity reading – without irritating the horse's skin – with the amount of hair the horse has on its body. The textrode could also be ideal as it allows more direct and prolonged contact with the skin, and its effectiveness could not be affected by the amount of sweat the horse produces, but can actually help improve the reading due to increased lubrication, if coated with a conductive elastomer, like rubber (Muhlsteff & Such, 2005). A rough visualisation of where the textrode would possibly be placed for the best possible reading is shown in Figure 3.

Figure 3 - Conceptualisation of where textrode could be placed

4.2 Respiration

Respiration rates in horses are usually taken by counting the frequency of chest rise and fall cycles for a given period of time (Pilliner, 1994). The girth, the under-belly part of the saddle, covers the entire cross-sectional area of the horse's chest. Because the girth is fitted in such a way to give the horse enough breathing space for the expansion of its chest when breathing, but tight enough to secure the saddle to ensure the rider does not fall off, a sensor that can handle deformation well needs to be used. The simplest and most feasible solution could be the use of conductive yarns attached to an elastomer, sewn onto the inner part of the girth to touch the horse directly. This could mimic the design of the RespiBelt (Atalay, Kennon, & Demirok, 2015), just done on a much larger scale to cover a larger cross-sectional area. Since knitted structures are generally characterized by their high flexibility, good skin contact, breathability and high elastic recovery, they are more desirable for strain sensing in comparison to woven structures. The conductive yarns should be integrated into the structure during the production stage of the fabric as the production stage could be reduced to one step in contradistinction to the multi-stage creation of coated fabrics (Atalay et al., 2015). A rough conceptualisation of how this would be placed is shown in Figure 4.

When it comes to deformity, shape memory alloys could be an ideal material candidate, as they are threads with a trained memory shape, that can easily blend into textile substrates (Van Langenhove & Hertleer, 2004). Combining this actuator with optical fibres, which possess a higher tensile strength than conductive yarn, could also be an ideal solution to monitoring respiration.

Figure 4 - Conceptualisation of where conductive yarn and elastomer could be placed

4.3 Temperature

The temperature of a horse is most accurately taken with a thermostat from its rectal cavity (Pilliner, 1994). Due to the already established invasiveness and overall discomfort for the horse, trying to incorporate smart fabrics into this health state is not at all feasible. Some groomers check breath temperature by putting their hands in front of the horse's nose . This is in no way done to obtain an accurate reading, but more so to gain an overall feel of the horse's internal temperature.

If further studies are taken to somehow link that the temperature is the same from both ends of the horse, there may be a small window for automation. The bit is part of the bridle that goes into the horse's mouth, which aids the rider with steering and reigning in the horse. Most performance horses wear them, and they are typically made of steel. Because it is made of steel, the conductive property could be used to measure temperature, without extra incorporation of smart fabrics at all. As it stands, it is not at all feasible to incorporate smart fabrics in monitoring this health state.

5 Conclusions

By introducing smart fabric sensors into riding gear, health data can now be logged in real-time – instead of being batch collected – to help establish a better THR normal range, as reading as more accurate and a wider range is given. Due to the current ways of measuring THR in horses, only H and R are feasible at the moment, with the use of textrodes and conductive yarn respectively. If there is more advancement in the research with the application of smart fabrics, more states and conditions could also have their monitoring automated.

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