HARVESTING TECHNICAL NOTE

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Evaluation of EMG Sensors for Biofeedback

Summary

An evaluation was conducted of a commercially available electromyography sensor to explore data accuracy and reliability when used in a complex work environment. The goal was to determine the capabilities of the 'Resility EMG Biofeedback sensor' and its suitability to the research project. Testing took place in both a controlled office setting and on a machine operator while working in an operational forestry environment. Testing resulted in the formulation of a list of criteria with desired specifications and requirements for a product. Significant issues were discovered during the deployment of the Resility EMG device. For future work, products must be carefully selected, validated by testing to be sophisticated enough to be used in a complex work environment such as a harvesting machine.

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Introduction

Electromyography (EMG) is a diagnostic procedure to assess the health of muscles and the nerve cells that control them (motor neurons) by studying electrical signals in the muscles.

Biofeedback is a technique used to learn to control some of the body's functions, such as muscle contraction. This type of biofeedback involves placing sensors over the muscles with an electromyograph to monitor the electrical activity that causes muscle contraction. This feedback helps the subject, such as a harvesting machine operator, to make subtle changes in their body, such as relaxing certain muscles, to achieve desired results like reducing pain or improving a health condition or physical performance.

Since the 17th century, EMG has been utilised by many interested in the electrical stimulation of muscles. The nervous system controls muscle movement, and this movement is caused by the relaxation and contraction of muscle fibre. Muscle fibre, groupings of specialised cells, contract following a chemical reaction and conversely relax when the chemical reaction stops (Kale & Dudul, 2009; Raez *et al.*, 2006). These contractions and relaxations are signals, also called myoelectrical activity, that electromyograms monitor. Electrodes are vital to an EMG setup (Figure 1).

Figure 1. Self-adhesive electrodes. Source: (Dobrucki et al., 2016)

Placed on the surface and intramuscular levels of the skin, electrodes act as an electrochemical transducer, converting signals from the muscles (Cram, Kasman, & Holtz, 1998; Dobrucki *et al.*, 2016). Electrodes use metallic contacts surrounded by conductive hydrophilic gels, pastes or a 'dry' connection using adhesive tapes to form an electrolyte connection with the skin (Roy *et al.*, 2007). Throughout history, improvement in electrode conductivity has improved the ability to detect and interpret muscle movement (Cram *et al.*, 1998; Raez *et al.*, 2006).

EMG is a critical tool in physiological research and technology development, with many possible applications. The primary application for EMG exists in the medical field in diagnosing neuromuscular and neurological disorders (Raez *et al.*, 2006). Wearable health monitors with

inbuilt EMG sensors have rapidly become popular on the market (Figure 2).

Figure 2. The BioStamp is a waterproof sticker containing sophisticated real-time vital signs and activity tracking. Source:
https://ehealthnews.co.za/biostamp-wearable-sensor/

Wearable sensors are designed to collect and transmit data in real-time via a wireless or wired link (Ng & Reaz, 2017; Zuhra *et al*., 2017). Furthermore, EMG sensors can be incorporated into clothing and tattoos (Ferrari *et al*., 2018; Ramasamy & Varadan, 2018). EMG signals have been used to drive mechanical prosthetic replacements (Mahanth *et al*., 2017). Another project used EMG signals to allow speech in those without vocal cords and who cannot verbalise due to medical conditions (He *et al*., 2020; Manabe *et al*., 2003).

Supplementary to the EMG system is a function called Biofeedback. Biofeedback is a method used to visualise and improve physiological function and state. This function feeds back information to the monitored individual with a real-time activity display, allowing the subject to observe the connected group of muscles and consciously manage the contraction and relaxing of these targeted muscles. Biofeedback can display other vital signs, such as pulse rate, respiration rate, and electrical activity in the brain. Not only can biofeedback be used to treat stress, anxiety and depression (Thabrew *et al*., 2018), it can also optimise the performance of musicians and athletes (Deschodt-Arsac *et al*. 2018).

EMG signals can be incredibly complex and require optimisation by specially designed algorithms, as they are prone to noise (from both external and internal inputs), artefacts and instability in signal amplitude (Kale & Dudul, 2009; Raez *et al*., 2006).

To further complicate matters, electrodes used during an EMG can significantly affect the signal quality. The type of electrode interface (gel, paste, dry), skin preparation and location can cause issues. Any change in the physical properties of the skin, such as body temperature increase and perspiration, can deform the electrode contact and create noisy signals (Roy *et al*., 2007). In addition, there is also the interference of cross-talk activity from neighbouring muscle (Roy *et al*., 2007).

Considering this inherent complexity, how do at-home miniaturised wearable devices maintain the integrity of data the customer receives? Can the customer freely obtain software and hardware details of these at-home commercialised devices to begin assessing these devices? Without rigorous and independent testing, there is no way to make informed decisions as a consumer. During an internship, Scion researcher Brooke O'Connor investigated these questions by evaluating one such wearable device.

Internship Project

The internship project is a continuation of past research conducted by Scion to evaluate the potential importance of using EMG biofeedback in forestry operations (Parker & Wright, 1999). In recent times, the forest industry has shifted to mechanised harvesting and processing. A machine operator sits in the machine cab for long periods in one position and uses levers to control the machine's mechanisms. These workstations can be challenging for muscles and cause ongoing shoulder and neck pain (Attebrant *et al*. 1997; Macků & Dvořák, 2013).

The commercial market for wireless wearable technologies is ever-expanding, including products with inbuilt EMG sensors. Despite this, very few products on the market have been independently tested and validated, making them questionable for research purposes (Peake *et al*., 2018). The Human Factors team at Scion

recently purchased an affordable at-home EMG sensor with biofeedback capability. The 'Resility' EMG device required testing to assess its aptitude for the research project. The 'Resility' EMG biofeedback sensor is only mentioned in the literature in one book chapter by McKain (2019) and has not been independently verified and appears only to be a supplementary tool for building stress resilience.

Objective
To independently evaluate the 'Resility' EMG biofeedback sensor to determine if it meets the specifications and requirements for its intended purposes in the Scion research project. The performance of the EMG sensor is critical to ensuring that data is accurate and reliable for analysis.

Milestones

i. Conduct controlled office testing
ii. Deploy device in the field (real life setting) on a machine operator (Figure 3.)

Figure 3. Typical harvesting machine in New Zealand

Method

Materials
The EMG sensor chosen for testing was the Resility Bluetooth EMG Muscle Activity Sensor which has the following features:

- Weight 25g
- Dimensions 72 mm x 29 mm x 12 mm
- Compatibility for iOS and Android with Bluetooth wireless connection
- Threshold alarm providing visual or auditory feedback for Biofeedback capability

The Resility sensor comes with surface electrodes (Covidien Kendall Disposable Surface EMG/ECG/EKG Electrodes 1 3/8" (35mm); a high-quality disposable electrode with a Snap-On connector and a unique, patented pre-gelled adhesive side.

Biofeedback was displayed to the subject via an iOS device (iPhone 5) during testing. In the forestry machine a phone stand was required. Hand sanitiser (70% ethanol) was used to prepare the electrode surface. This was used to remove dead skin cells and perspiration.

Testing Protocol
Testing was undertaken on one individual in both a controlled office setting and an active forestry machine. Subjects were healthy and had no history of injuries or neck-shoulder pain. During office testing, the biofeedback device was on display on the desk next to the subject, showing their muscle activity in real-time. The biofeedback device was anchored in the forestry machine to not interfere with the operator's view or move during operation.

Disposable adhesive electrodes were connected to the sensor, and the sensor initiated. The upper trapezius muscle on their right-hand shoulder was selected for recordings. Placement of the electrode on the muscle is essential to the accuracy of recordings. To get the best results from surface EMG recordings, it is crucial to understand the muscles from which the EMG signal is being extracted (Zahak, 2012). The skin

was prepared using a hand sanitiser and a paper towel. Electrodes were installed whilst the participant was standing erect. The recording was started using the display on the app; a timer starts indicating the recording has begun (Figure 4).

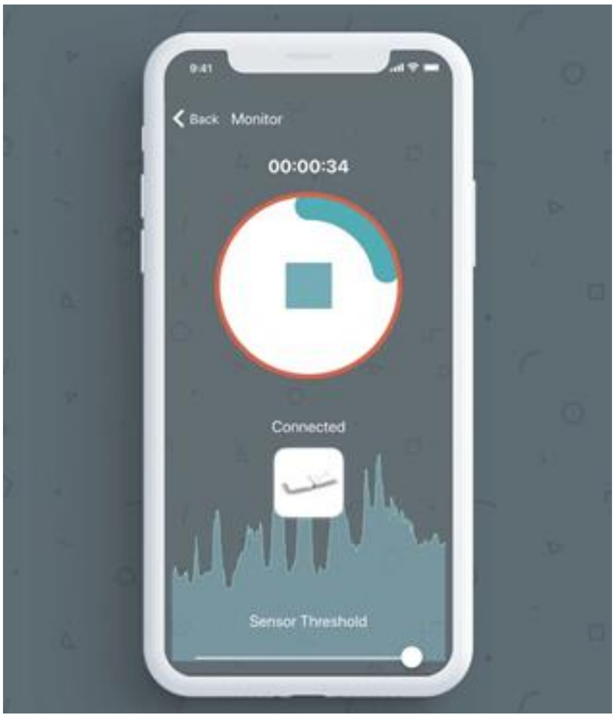

Figure 4. Resility App user interface. Displaying recording time, EMG recording and threshold slide bar (at the bottom of the screen). Image from https://resilityhealth.com/product/bluetooth-emg-biofeedback-sensor/

A threshold level was set using the 'Sensor Threshold' slide bar and is displayed by the red outer circle on the app screen (Figure 4). There is an alarm (noise and vibration) to feedback to the operator when they go over a set threshold. During testing, the threshold was set to mid-way to test if the subjects notice the alarm. Recorded sessions can be downloaded from the Xen app login through the Resility website. Data is displayed in charts for straightforward interpretation.

A user feedback survey was conducted with the participants following the completion of testing. Questions included: Did you notice the device? If so, did it impede your work? Did you notice an alarm? Did you find yourself monitoring the live muscle feed during working? Did you alter or control any activity based on the output of the screen?

Results

Office Testing

A recording was taken of 626 seconds (10 minutes). The recording went well with no apparent problems with recording data. Results showed a range settling between 1-1.8µV, ignoring the outlying peaks (Figure 5).

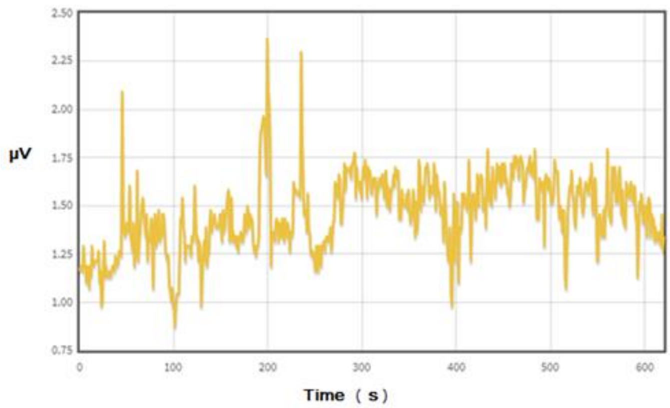

Figure 5. Office participant recording

User feedback reported was that the device was comfortable, and they found that they were proactively trying to relax their muscles as they enjoyed watching it on the screen. The three peaks in the recording could be explained by the subject wanting to test exceeding the set threshold and desiring to hear the alarm, which they said they heard three times. The screen was easy enough to see for the participant.

Forestry Operator Testing

Testing was conducted with a representative from Rayonier Matariki Forests, New Zealand's third largest forestry company. The selected participant was operating a CAT logging machine with a grapple, whose primary job was fleeting (Figure 6). Fleeting is the act of moving logs in to correct graded stacks for loading an imminent log truck.

Figure 6. Forestry site EMG testing setup

Field testing
Unfortunately, upon fieldwork completion, it was discovered that the sensor failed to upload the data to the Xen platform due to connection instability. As the sensor does not possess an onboard memory, when it loses connection and the recording has not been stopped, the session data is lost. This failure led to all active work recorded being erased.

If the Scion researchers were to use this sensor in upcoming trials, this would become a serious issue. However, the operator could still see the live muscle activity display throughout the work task and said there was no indication that the data was interrupted or no longer recording. That being the case, the user experience and feedback were the only data that could be used for the time the operator was working.

Fortunately, there was a recording of the operator during the setup period when the subject was waiting to continue working, as shown in Figure 7. This recording lasted 423sec (7 minutes) during the setup phase of the experiment. Figure 7 shows the EMG recording from the operator during idle time settling in with a range of 1-2.7μV. Interestingly, the operator was recorded at a higher activity range in comparison to the office worker. Thus, creating more interest to acquire successful recordings of an operator working.

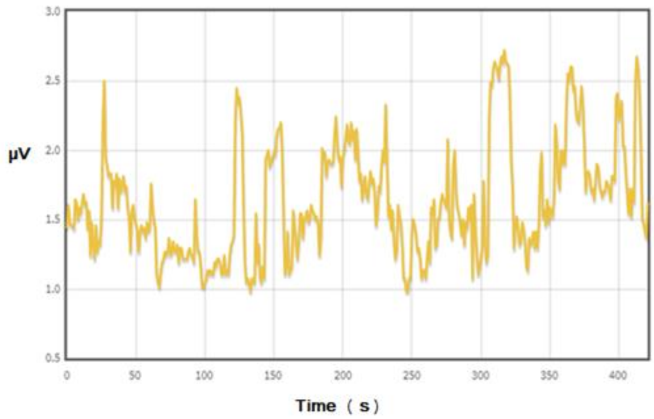

Figure 7. Forestry operator recording during downtime

The operator mentioned that the screen visibility was an issue, both with the screen size and brightness level. This is an important revelation as it shows the need for a more appropriate device size for users when using a technique like biofeedback. The compact layout of the display was described as problematic to see when looking at the live muscle activity (Figure 4). The operator reported only intermittently noticing the vibrating of the threshold alarm as the environment in a cab was too be noisy. The operator mentioned the sensor was comfortable and forgot it was there. Additionally, the biofeedback user interface is designed so that the operator would be able to stop the recording, causing data loss accidentally.

The operator did not report distraction and found themselves trying to relax while watching the display change on the screen, which is a great sign for future implementation. Furthermore, this awareness shows that the operator was willing to try and consciously manage those muscle groups.

Issues
Despite repeated attempts to contact 'Resility' via their customer service platform no correspondence has been returned. Disappointingly, we cannot confirm any basic electrical circuitry for signal acquisition, preamplification circuitry or configurations in the Resility EMG sensor. We were unable to confirm

whether the system is monopolar, bipolar or groundless in its configuration. Additionally, no comment can be made on the filtering settings that are used in the device. High pass, low pass or a band pass filtering is unknown. Noise within the signal plays a significant role in contaminating the raw EMG signal (Zahak, 2012). Therefore, it is crucial to investigate when selecting an appropriate electromyography sensor. Due to this, no technical evaluation was possible at this stage.

Discussion

Considering the inherent complexity in a forestry machine, the 'Resility EMG Biofeedback sensor' was regarded as unsuitable for the upcoming research project. The primary reason was data acquisition failure and complete dataset loss during field testing due to a momentary loss of connection. In conclusion, the 'Resility EMG is unsuitable due to the following critical reasons:

- Lack of onboard memory on the sensor, leading to complete data loss if the connection is compromised. This sensor was deemed unreliable and a risk.

- No electrical or technical evaluation was possible due to a lack of information from 'Resility'. As a result, researchers could not verify the accuracy or reliability of the data output from the device.

- Inability to see or change any device settings

- Data was not freely accessible

- Biofeedback graphical display was poorly designed for use in forestry cabin

- Customer support was non-existent

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Future Steps

A list was devised from what the 'Resility' sensor lacked in order to elucidate what is essential in an ideal EMG sensor system. As a result, the following criteria will deliver desired results for the project:

- Data is stored in an onboard memory eliminating any 'holes' in the data if communication is poor or the user moves out of range.
- Wireless Surface EMG
- The user can alter the biofeedback display
- Digital WIFI communication using standard IEEE protocols allowing the sensors to work in critical environments as the system automatically selects a freely available channel for communication. This is an important feature in a forestry setting.
- Groundless technology removes the need for a ground reference electrode.
- Gain is controlled by system software for ease of use.
- Probes have variable geometry electrodes that adapt to the positioning of the probe on the subject.
- Probes are lightweight to minimise any artefacts generated by the probe's movement and maximise movement detection from the participant.
- Ongoing product and technical support

A possible option is the 'BTS FREEEMG', a sophisticated network of wireless miniaturised probes that can detect weak signals accurately and reliably, satisfying the desired criteria above. This product is employed by medical professionals and is independently validated. Most importantly, sensors are equipped with internal memory to ensure uninterrupted recording in temporary connection loss (BTS).

Additional research considerations

For research to be ethical, it should be designed to minimise harm and risk, and the potential benefits of the study should outweigh those remnants. The protection of privacy and commitment to confidentiality is paramount. Confidentiality is respecting the dignity of participants and should be prioritised when

promoting the integrity of the research. Data guardianship is a key consideration for my future work. When conducting research, we should always be considering any relevant physical, psychological, cultural, economic and privacy harms to the participant (NEAC, 2020). An example of harm is the economic harm to the forestry operator by slowing workflow and participating in the study. In future work, ethical considerations will be vital in designing and framing projects.

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