



THE UNIVERSITY OF
WAIKATO
Te Whare Wānanga o Waikato

Research Commons

<http://researchcommons.waikato.ac.nz/>

Research Commons at the University of Waikato

Copyright Statement:

The digital copy of this thesis is protected by the Copyright Act 1994 (New Zealand).

The thesis may be consulted by you, provided you comply with the provisions of the Act and the following conditions of use:

- Any use you make of these documents or images must be for research or private study purposes only, and you may not make them available to any other person.
- Authors control the copyright of their thesis. You will recognise the author's right to be identified as the author of the thesis, and due acknowledgement will be made to the author where appropriate.
- You will obtain the author's permission before publishing any material from the thesis.

Biofeedback on Forestry Machine Operators

A thesis
submitted in fulfilment
of the requirements for the Degree
of
Master of Science (Research) in Computer Science
at

The University of Waikato
by

Brooke O'Connor



THE UNIVERSITY OF
WAIKATO
Te Whare Wānanga o Waikato

2023

Abstract

Aotearoa, New Zealand, has cultivated a sustainable and thriving forest sector, establishing it as a primary industry. Throughout the years, there has been a significant transition in the forest industry towards using mechanised methods. Operating machines and maintaining precise hand and arm movements can lead to muscle strain in operators. This strain is harmful and increases the risk of work-related musculoskeletal disorders. This thesis aims to utilise electromyography sensors to observe the muscle activity of operators in forestry machines while carrying out harvesting operations. The objective of this research is to examine the potential advantages of biofeedback training in enhancing operators' physiological functioning through visual feedback. Experimental testing phases were required prior to deployment in the field. The primary trial details electromyographic recordings gathered through field measurements using electromyographic (BTS FREEEMG 1000) sensors to assess the activity of the upper trapezius muscles. Recordings were conducted on 14 operators performing operational harvesting tasks. Tasks included felling, processing, loading, shovelling, fleeting, and sorting. *Findings:* EMG Biofeedback training allowed operators to observe and consciously control the contraction and relaxation of the upper trapezius muscles. Overall, the average muscle activity decreased during biofeedback training in most recordings. Results highlight the potential of EMG biofeedback training as a preventative tool for work-related musculoskeletal disorders in New Zealand.

This research is conducted as part of a master's project in collaboration with Scion and Waikato University with funding from the New Zealand Forest Growers Levy.

Keywords: forestry, biofeedback, mechanised forestry, work-related injuries, logging, sensors, BTS FREEEMG 1000, electromyography, human factors, ergonomics.

Acknowledgements

I would like to express my profound gratitude to my supervisors, Associate Professor Judy Bowen from Waikato University and Dr Richard Parker from Scion, for their invaluable guidance and support throughout this research endeavour. Your unwavering patience and encouragement have played a pivotal role in the success of this study.

I would like to express my gratitude to the New Zealand Forestry Research Institute, Scion, for granting me permission to conduct this project as part of my Master's degree. I am also deeply thankful to Keith Raymond, the Harvesting Programme Leader at Forest Growers Research Ltd, for his invaluable support in making this study a reality.

I would like to extend a special thank you to Travis Terry from West Coast Ngai Tahu Forestry for his immense contributions towards assisting me in completing my field work. Your guidance, assistance with participant selection, and overall support have been instrumental in the success of my research. I truly appreciate the time and effort you dedicated to helping me.

I want to give special recognition and thanks to Simon Brand of Brand Logging Canterbury. Your expertise, guidance throughout the process, including participant selection and your hands-on assistance made a significant difference in facilitating my work. Your support was priceless and I am immensely grateful for it.

I also want to acknowledge Matthew Batty from Martock Holdings for his instrumental role in facilitating sensor testing on an agricultural tractor using the BTS FREEEMG sensors. Not only did he provide vital support during the challenges encountered throughout this study but also served as an invaluable sounding board. Your unwavering support has made all the difference.

To all the participants who took part in this trial, I want to offer my heartfelt thanks. Without each one of you, none of this would have been possible.

I would like to extend my sincerest and heartfelt gratitude to the members of my human factors team. To our captain, Dr Richard Parker, I am deeply thankful for your invaluable assistance as a willing participant, wise counsel, and unwavering support that has kept me motivated throughout this journey. I also want to extend a heartfelt appreciation to Brianny Hooper for her constant encouragement, wealth of knowledge in working with people, unwavering support during fieldwork and every step of this process. Without both of you, none of the achievements attained thus far would have been possible, and for that I am eternally grateful.

Thank you to Rob Whitton and Marie Joo Le Guen for your support and advice during this process.

Lastly, I extend my gratitude towards everyone who provided assistance along the way in various capacities - your contributions have not gone unnoticed or unappreciated.

Thank you all once again; it means more than words can convey.

Presentations arising from this research

Poster presentation at The Council on Forest Engineering (COFE), International Symposium on Forest Mechanization (FORMEC), and International Union of Forest Research Organizations (IUFRO) Division 3 2022 Joint Conference.

Biofeedback on Forestry Machine Operators. The Human Factors and Ergonomics Society of New Zealand 2023 Conference. Arrowtown 5-7 July 2023.

Table of Contents

Abstract.....	iv
Acknowledgements.....	v
Presentations arising from this research.....	vii
List of Tables.....	xi
List of Figures.....	xi
List of Appendices.....	xi
List of Abbreviations.....	xii
Chapter 1 Introduction.....	1
1.1 Background.....	1
1.1.1 Forestry machine operators.....	2
1.1.2 Health impacts.....	4
1.2 Aim.....	5
1.3 Approach.....	6
1.4 Project aims.....	6
1.5 Hypotheses.....	6
1.6 Funding.....	7
1.7 Thesis outline.....	7
Chapter 2 Literature Review.....	8
2.1 Introduction.....	8
2.2 Musculoskeletal disorders.....	9
2.3 Electromyography.....	9
2.3.1 EMG applications.....	11
2.3.2 EMG in forestry.....	12
2.4 Biofeedback training.....	13
2.4.1 Biofeedback training applications.....	14
2.4.2 Biofeedback training in forestry.....	16
2.5 Discussion and conclusion.....	16
Chapter 3 Pilot Trial.....	17
3.1 Introduction.....	17

3.2	Aim.....	17
3.3	Methods.....	18
3.3.1	Ethical considerations	18
3.3.2	Equipment.....	18
3.3.3	Experimental design	19
3.4	Results.....	22
3.4.1	Office-based worker results	22
3.4.2	Forestry operator results.....	23
3.5	Results and discussion	23
3.5.1	Findings	23
3.5.2	Recommendations.....	25
3.6	Conclusion.....	27
Chapter 4	Methods.....	28
4.1	Ethical Considerations	28
4.2	Equipment.....	28
4.2.1	EMG biofeedback system selection	28
4.2.2	EMGAnalyzer software	29
4.3	Experimental design	30
4.3.1	Electrode placement	30
4.3.2	Biofeedback display	31
4.3.3	Testing phases.....	32
4.3.4	NASA TLX	34
4.3.5	Locations	35
4.3.6	Participants	35
4.3.7	Experimental design	37
4.3.8	Testing protocol	38
4.3.9	Data analysis	39
4.3.10	Signal Processing.....	40
Chapter 5	Results.....	41
5.1.1	<i>p</i> value	41

5.2 Left side results.....	42
5.3 Right side results	44
Chapter 6 Discussion	46
6.1 Results discussion	46
6.2 Trial discussion	49
6.3 Future research	51
6.4 Strengths and limitations.....	53
6.5 Reflection.....	54
Chapter 7 Conclusion	56
References	57
Appendix.....	65

List of Tables

Table 1 Participant Details.....	37
Table 2 Left side results	43
Table 3 Right side results	45

List of Figures

Figure 1 Mechanised extraction systems.....	2
Figure 2 Forestry machine components.	3
Figure 3 Comparison in cab layout between harvester machines.	4
Figure 4 Thesis outline.	7
Figure 5 Biofeedback.....	14
Figure 6 Resility Wireless EMG Biofeedback mobile app display	20
Figure 7 Office participant EMG recording.....	22
Figure 8 Biofeedback display installation.....	25
Figure 9 BTS FREEEMG 1000 sensor placement.....	31
Figure 10 BTS FREEEMG 1000 biofeedback display	32
Figure 11 Machine cab limitations	34
Figure 12 Control data collection process	38
Figure 13 Biofeedback data collection process	39
Figure 14 Signal analysis process	40
Figure 15 EMG signals on biofeedback display.....	48

List of Appendices

Appendix A Terminology	65
Appendix B Ethics approval document	66
Appendix C BTS FREEEMG 1000 information.....	67
Appendix D Participant handouts	68
Appendix E Illustration of operational tasks	70
Appendix F Signal analysis of signal quality	71

List of Abbreviations

CTL	Cut to Length
WT	Whole Tree
RSI	Repetitive strain injury
CTS	Carpal tunnel syndrome
WRMSDs	Work-related musculoskeletal disorders
MSDs	Musculoskeletal disorders
MMG	Mechanomyogram
EMG	Electromyography
SWE	Shear wave elastography

Chapter 1 Introduction

1.1 Background

In New Zealand, the forestry industry has undergone significant changes over many decades, particularly in how harvesting operations are done. Mechanised harvesting machines provide an alternative to motor-manual operations. Mechanisation is not a new phenomenon and has been reported on in the industry since the late 1970s (Kirk et al., 1997). Many mechanised ground-based harvesting systems are available and have proven productivity (Akay et al., 2004; Raymond, 2010) and safety advantages (Competenz, 2015; Kirk et al., 1997). Machine operators can achieve high production levels by working more consistently and longer hours. As a result, over an 8-hour day, a mechanised harvester can fell the same number of trees as three to four motor-manual fallers can produce in a day (Competenz, 2015). The benefits of mechanisation for contractors now mean fewer worker wages and places for the remaining workers to remain protected in a machine cab (Kirk et al., 1997). Safety is improved by eliminating, isolating, or minimising a range of hazards generally faced by motor-manual workers (Competenz, 2015). Many people in New Zealand rely on machines to carry out forestry operations, which entails a wide range of challenging tasks.

Mechanised harvesting and processing refer to the utilisation of machinery to carry out tasks such as cutting down trees, removing branches, and processing by cutting to specific lengths and debarking. Numerous machines and attachment heads have been developed for the purpose of harvesting, processing, and handling logs (MacDonald, 1999). Different heads are available as attachments that can be mounted on either a boom or the base carrier's chassis. These mechanised systems are typically used in areas with relatively flat through to rolling terrain. These ground-based operations exist as a maximum safe operating range in slope gradient-limits forestry machines. Slopes are harvested by cable yarding and more recently cable assist systems (Visser, 2015).

In these ground-based harvesting operations, the most commonly used extraction systems are the Cut to Length (CTL) and Whole Tree (WT) extraction systems

(Häggström, 2015; Visser, 2015) (Figure 1). In the CTL system, the harvester operator manually selects, cuts down, and processes the trees by removing branches and cutting them into logs. These logs are then arranged in piles for accessible collection by the forwarder, who is responsible for transporting the logs to the landing or roadside. In contrast, the WT system utilises a machine equipped with a cutting attachment head to cut down trees, a skidder to remove the whole stems from the stand and a processing machine to cut them into logs. Both systems use a loader to sort, fleet, and load logging trucks as they pass through the landing. It is standard practice to maintain adequate distance between all working machines.

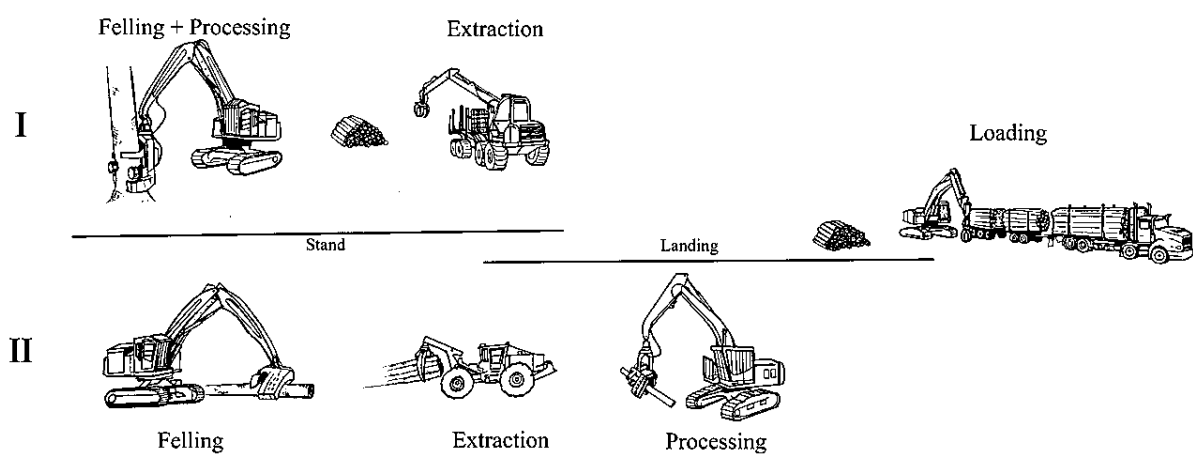


Figure 1 Mechanised extraction systems.

The illustration shows the workflow using the two extraction systems. I: Cut-to-length (CTL) extraction system. II: Whole tree extraction system (WT).

1.1.1 Forestry machine operators

As machine operators, individuals must navigate large self-propelled forestry machines and machines configured as forestry machines. While the process of logging itself is relatively straightforward, involving forestry machines to convert trees into logs and load them onto log trucks, there are variations in terms of machinery types, tasks and decision-making responsibilities placed upon operators (Häggström, 2015).

Operators are responsible for controlling various aspects of their machines, such as the tracks, upper unit swing functions, the hydraulic boom and stick movements, along with attachment head controls (Figure 2).

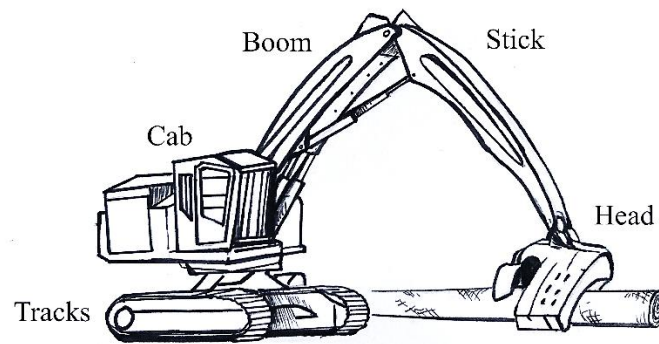


Figure 2 Forestry machine components.

This illustration provides a visual representation of the key parts of a forestry machine.

The complexity involved in operating these machines can differ significantly. The process of effectively operating processors and harvesters involves intricate coordination, which is why most operators start their careers in more straightforward machines. Common starting points include loaders, where tasks such as sorting, fleeting, and loading are carried out, as well as extraction machines that extract stems and logs to designated landings. Harvester and processor machines feature more complex head attachments that demand a higher level of control input (Gellerstedt, 2002; Hansson, 1990). Operating forest machinery is known to be mentally demanding as it requires extensive use of levers, joysticks, and controls for controlling various functions of the machine. However, with time and experience operating these machines becomes second nature and an automatic behaviour (Rasmussen, 1983; Gellerstedt, 2002).

Generally, both hands are engaged while operating these machines. In modern forestry machines, operators use two multifunctional levers or joysticks located in front of the arm rests. These levers or joysticks vary in layout and function depending on the manufacturer, machine type and age of the machine (Figure 3).

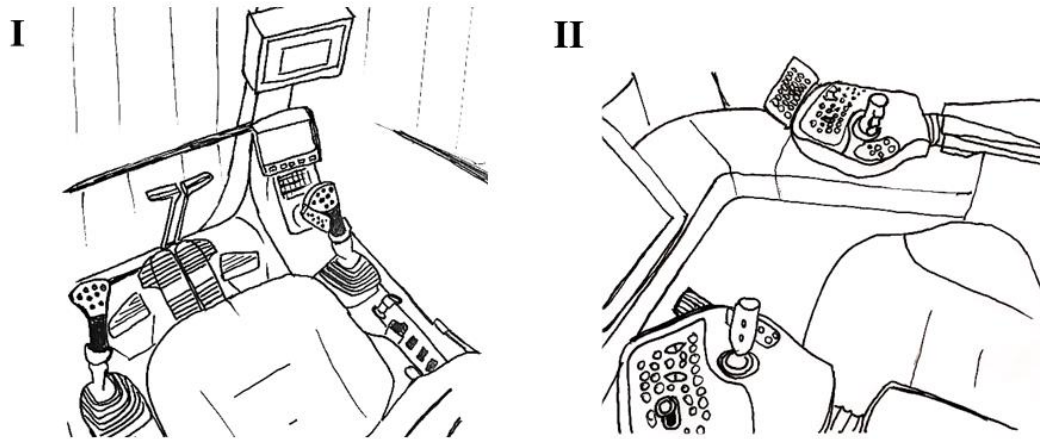


Figure 3 Comparison in cab layout between harvester machines.

This illustration shows a comparison of the variation that exists between forestry cab layouts in harvesters. I: 2014 Komatsu PC160. II: 2019 John Deere 1270G.

In addition to the intricate nature of the tasks, many operators are faced with the challenge of navigating large machines through dense forests and having to manoeuvre and process large and heavy trees while contending with unpredictable terrain and environmental conditions.

1.1.2 Health impacts

In New Zealand, the forest industry has one of the highest incidence rates of work-related injury claims in 2021 (StatsNZ, 2022). The strain associated with operating machines and maintaining the highly coordinated movement sequence of the hands and arms has increased the risk of health concerns such as muscle fatigue. This fatigue is typically detrimental and can significantly escalate the likelihood of sustaining serious injuries (Al-Mulla et al., 2011; Attebrant et al., 1997). Common complaints from machine operators include injuries to their neck, arms, and spine, which is a serious problem (Axelsson & Pontén, 1990). Based on research conducted by Ding et al. in 2000 and Nussbaum et al. in 2001, it has been suggested that muscle fatigue plays a crucial role in the onset of musculoskeletal disorders affecting the upper limbs. These studies emphasised the link between repetitive tasks and the development of wrist and hand issues, such as tendon problems, carpal tunnel syndrome (CTS) and discomfort in the hand and forearm (Hansson et al., 2000; Muggleton et al., 1999).

According to Paini's (2019) study, machine operators were observed to perform over 30 thousand repetitive actions in a single workday. This finding suggests that these operators face a significant risk of developing Repetitive Strain Injuries (RSIs) and Musculoskeletal Disorders (MSDs).

MSDs encompass a broad spectrum of painful injuries that affect multiple anatomical structures, such as muscles, ligaments, bones, tendons, blood vessels and nerves (Worksafe, 2022). They occur when work causes or adds to pain, discomfort, or injury (Buckle, 2005). Globally, governments are particularly interested in preventing work-related injuries due to the strain it puts on the health care sector and increases unemployment costs (Axelsson & Pontén, 1990; Buckle, 2005; McLean & Rickards, 1998). Unfortunately, the change to mechanisation has seen upper body injuries increasing among machine operators, resulting from long hours repetitively moving the machine's controls (Axelsson & Pontén, 1990; Kirk et al., 1997). MSDs can significantly affect the quality of life of forestry workers by restricting their ability to work and can result in long-term disability. Given the nature of this work, it is crucial to explore innovative approaches to reduce the risk of musculoskeletal disorders. One such approach is the utilisation of electromyography and biofeedback training in forestry cabs.

Forestry terminology is further defined in Appendix A Terminology.

1.2 Aim

This thesis will contribute towards the growing literature on the practical applications of using sensors in harvesting operations. This research aims to evaluate the practicality of using this innovative technology known as electromyography, to analyse the muscle activity of operators in forestry machines during harvesting operations. The use of biofeedback training will be evaluated as it could become a valuable tool to mitigate MSDs while operating machinery.

1.3 Approach

Research utilising biometric sensors on forestry machine operators during operations has been conducted (Gellerstedt, 1997; Jankovský et al., 2018; Macků & Dvořák, 2013). Studies have been conducted on harvesting simulators while using EMG biofeedback (Dvořák et al., 2016; Natov et al., 2016). However, the use of biofeedback as a training tool in forestry machines still requires evaluation.

The current literature will be reviewed, followed by testing and field trials to investigate the validity of using a biofeedback training system as a preventative tool in harvesting operations. The primary focus of this study is on the trapezius muscle due to its suspected involvement in work-related musculoskeletal disorders (Cescon et al., 2008).

1.4 Project aims

The objectives of this project are as follows:

- I. Conduct an examination of the existing body of literature pertaining to the utilisation and effectiveness of EMG and biofeedback training, with a specific focus on its application within the forest industry.
2. Assess the feasibility and viability of implementing an EMG biofeedback training system in forestry machines.
3. Quantify any potential differences in muscle activity exhibited by operators performing biofeedback training.

1.5 Hypotheses

Does EMG biofeedback training affect muscle activity in operators?

- Null hypothesis (H₀): EMG biofeedback training does not affect muscle activity.
- Alternative hypothesis (H_a): EMG biofeedback training affects muscle activity.

1.6 Funding

Forest Growers Levy in New Zealand generously provided funding for this initiative.

1.7 Thesis outline

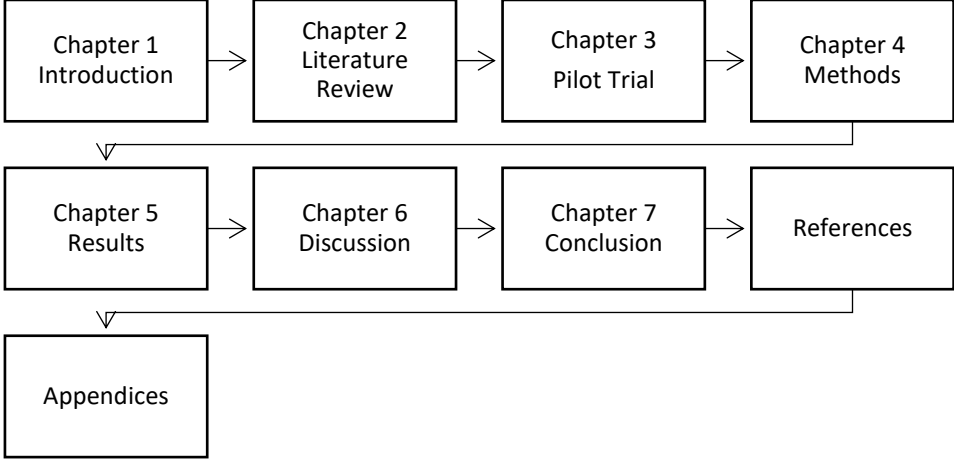


Figure 4 Thesis outline.
Outline details the sections contained in this thesis.

Chapter 2 Literature Review

This chapter provides an overview of the health concerns faced by operators of forest machinery. An introduction is provided outlining the fundamentals of electromyography signals and their analysis, serving as a foundation for understanding subsequent content. The following sections shed light on the various applications of EMG and biofeedback training, with a specific emphasis on their utilisation within forestry. Furthermore, this chapter summarises relevant literature pertaining to these subjects.

2.1 Introduction

The forest industry holds significant importance in the economy of New Zealand, contributing an annual gross income of around \$6.6 billion a year, making it the country's fourth largest export earner (MPI, 2023). This sector is responsible for creating tens of thousands of employment opportunities for individuals residing in New Zealand. The industry comprises various stages, including silviculture, harvesting, processing, and distribution. Forest workers are responsible for carrying out these stages and are an essential part of the forest industry.

Forestry is one of the most dangerous occupations with a high accident frequency and has initiated many studies on worker safety (Klun & Medved, 2007; Lilley et al., 2002; Melemez, 2015; Tsioras et al., 2014). Forest workers face various health and safety risks due to the nature of their work. Their safety is critical in ensuring the sustainability and productivity of the industry.

As New Zealand forest workers move into machines, injuries sustained during motor-manual operations reduce but these machines have created another generation of musculoskeletal concerns (Harstela, 1990).

2.2 Musculoskeletal disorders

Work-related musculoskeletal disorders (WRMSDs) of the neck, shoulders, lower back, and upper limbs are commonly reported in forestry machine operators (Axelsson & Pontén, 1990; Gallis, 2006; Ghaffariyan, 2016). The primary factors contributing to these injuries include prolonged periods of sitting, high work intensity while maintaining fixed and ergonomically unsuitable positions, and short cycles of repetitive movements (Axelsson & Pontén, 1990; Hansson, 1990; Gallis, 2006). Silva et al. (2014) found that during the entire workday, workers' upper limbs are heavily utilised, predominately performing repetitive movements. Even machines with the highest ergonomic ratings are tiring for the operators, especially in combination with great attention to the task (Gellerstedt, 1993; Harstela, 1990). The physical demands of their occupation place forestry machine operators at a heightened risk of WRMSDs (Miranda et al., 2001).

WRMSDs can significantly impact forest workers' health, well-being, and ability to perform their jobs effectively. Reported health concerns range from minor muscle sprains and strains to more severe conditions, including herniated discs and carpal tunnel syndrome (Paini et al., 2019; Santos et al., 2016). In addition to causing pain and discomfort, these health concerns can lead to lost wages, reduced productivity, and long-term disability.

Overall, the literature suggests that work-related MSDs are a significant problem among forestry workers and effective interventions are needed to address this issue. Electromyography could offer insights and potential strategies for future interventions and preventative tools.

2.3 Electromyography

Electromyography, also known as EMG, is a technique used to examine the electrical signals within muscles. EMG can be used to understand the contraction and relaxation of muscle fibres, that are essential for movement. When the nervous system generates a signal, this process starts a chemical reaction within the muscle causing the muscle to contract. When the signal from the nervous system stops, the chemical process

stops and reverses, causing the muscle to relax (Gokgoz & Subasi, 2015; Kale & Dudul, 2009; Raez et al., 2006). These signals can be observed using EMG. In other words, EMGs capture and record the electrical currents generated during the contraction and relaxation of muscles (Gokgoz & Subasi, 2015). An EMG is performed with an electromyograph to produce an electromyogram, which transforms action potentials in data into graphs and numbers for observation and analysis. The instruments used to collect the electromyographic signals are called electrodes. Two types of electrodes are used: invasive and non-invasive electrodes; conductivity and placement vary between the two electrode categories (Raez et al., 2006).

The idea that muscles generate electricity can be traced back to Francesco Redi's work with electric eels circa 1666, as cited by Al-Mulla et al. (2011) and Raez et al. (2006). The capability of interpreting and detecting electromyographic signals has improved steadily since the 1930s-1950s. During the 1980s there were advancements in integrating electrodes which allowed for the mass production of small and lightweight instruments and amplifiers. This advancement made various suitable amplifiers readily available on the market. Additionally new cables were developed during this period that produced artefacts within the desired microvolt range. In recent years, extensive research has enhanced our understanding of surface EMG recording properties. As a result of these advancements surface electromyography has become increasingly popular in protocols for recording activities from superficial muscles. However deep muscle recording still relies on invasive electrodes (Raez et al., 2006).

To understand an EMG signal it is critical to understand how it is generated and measured. In their study, McManus et al. (2020) provide a thorough explanation which is summarised in the following section by the components that make up the signal. When muscles are activated, charged particles called ions move across the membrane of muscle fibres. This movement creates a current (I) which measures the rate of charge flow in Amperes (A) - electric charge per second. This electric current causes changes in the surrounding tissue potential. This electrical potential between two points is measured in Volts (V). At the surface of the skin various factors like resistance from muscles, fat structures and the skin itself affect this voltage measurement and this impedance using Ohms (Ω). The EMG signal measures these changes in voltage

distribution detected on the skin's surface due to activity happening within a muscle. By analysing these surface EMG signals we can gain insights into how our muscles contract and function during different activities. This understanding greatly contributes to studying physiology and has numerous potential applications.

Although the history of EMG can be traced back to the 17th century, it was not until the early 1980s that cables capable of producing the microvolt range became available, enabling the effective use of EMG (Raez et al., 2006). Over the past few decades, extensive research has led to a deeper understanding of recording properties and paved the way for surface EMG systems. These advancements have played a crucial role in minimising the impact of noise and addressing various factors, both extrinsic (such as electrode structure and placement) and intrinsic (including physiological, anatomical, and biochemical factors) (Al Mulla et al., 2011; Chowdhury et al., 2013; Kale & Dudul, 2009; Kale & Dudul 2009; Østensvik et al., 2019; Raez et al., 2006). The progress made in EMG signal analysis algorithms and equipment design has significantly improved the analysis and interpretation of EMG signals.

2.3.1 EMG applications

Electromyography (EMG) is an adaptable tool commonly used to diagnose neurological and neuromuscular conditions. EMG helps assess how muscles respond to signals from the brain and detects any irregularities. EMG proves valuable in diagnosing neuromuscular diseases, evaluating lower back pain, kinesiology, and motor control disorders (Raez et al., 2006). Additionally, EMG finds application in fields such as biomechanics, motor control, neuromuscular physiology and aiding physical therapy (Raez et al., 2006).

Researchers commonly utilise electromyography (EMG) technology to assess muscle fatigue. There are two approaches for investigating muscle fatigue: EMG and mechanomyogram (MMG). EMG is employed to evaluate the state of muscles, while MMG serves as its mechanical equivalent. Ongoing research focuses on employing autonomous systems in conjunction with EMG to detect and predict fatigue, yielding promising outcomes (Al-Mulla et al., 2011). This technological advancement has applications in domains like forestry. Fatigued muscles exhibit reduced energy

absorption capacity, rendering them susceptible to injuries. Consequently, researchers are devising measures to combat fatigue, employing EMG as an integral component of these innovative future tools.

EMG has proven successful in studies conducted across diverse research fields, primarily within controlled settings such as clinics and laboratories.

2.3.2 EMG in forestry

The volume of research conducted in forestry using EMG is somewhat limited. This is due to the difficulties of using biomedical instruments in more complex settings, like forestry. More recent improvements in EMG systems, such as portability, reduced power consumption, long-term sensor stability and the availability of comfortable wireless sensors with Bluetooth connectivity have expanded the possibilities for conducting research beyond controlled environments.

EMG sensors have become widely used in harvesting simulators and more recently in log trucks. A study by Dvořák et al. (2016) measured the mental workload of harvesting operators using EMG sensors. They specifically employed the Biofeedback 2000x pert system from Schuhfried Australia, located in Milton, Australia. Another study by Natov et al. (2016) used a harvesting simulator to evaluate workload by applying EMG sensors. Moreover, Škvor et al. (2022) and Škvor et al. (2023) effectively implemented EMG sensors on log truck drivers. Overall these studies showcase the increasing trend of utilising EMG technology to measure workload and performance in more complex settings.

Several research studies have been conducted to monitor the activities of forestry machine operators using EMG sensors. Gellerstedt (1997) used a PCM system to capture the EMG activity of operators with the aim of analysing their work elements and workload. Another study by Macků and Dvořák (2013) observed differences in muscle activity between harvester operations and other tasks using EMG sensors. Jankovský et al. (2018) measured both EMG and ECG to determine if work-related factors contributed to disease risk among machine operators. To address concerns about data accuracy, Østensvik et al. (2019) conducted a three-month study involving

sixty operators using EMG equipment on forest machine operators operating harvesters. These studies effectively demonstrated the deployment of EMG sensors in harvesting operations, providing insights into workload analysis, muscle activity comparisons, identification of risk factors for cardiovascular diseases among machine operators and improving data accuracy in research involving forest machinery operation.

It must be noted that despite technology advancements and the successful use of EMG sensor systems in forestry cabs in the literature it is acknowledged that challenges and difficulties still exist. As acknowledged by Macků and Dvořák (2013), the authors noted that the variability of the weather, challenging terrain, and demanding work conditions in combination with the requirements for electrode placement and a restricted transmission range of the sensors made collecting data in a harvesting machine challenging.

2.4 Biofeedback training

Biofeedback is often used with EMG to visualise the signal recorded by EMG sensors. This technique can also be used to display other physiological signals, such as heart rate (ECG) and brain activity (EEG). It is common to see researchers use a multimodal system, for example, utilising EMG and ECG in parallel. Figure 5 demonstrates how biofeedback can visually represent muscle contraction patterns. Through biofeedback, individuals can enhance their understanding of physiological functions within their bodies.

An extension of the biofeedback technique is its application in training individuals who are being monitored. This technique is called biofeedback training. This form of training involves actively engaging with real-time feedback over extended sessions, with the aim of achieving physiological improvements.

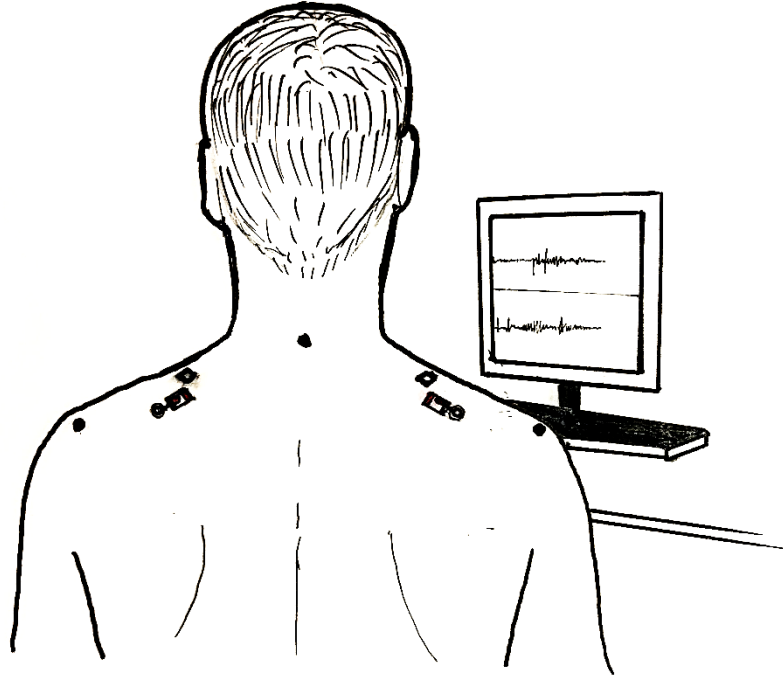


Figure 5 Biofeedback.

Illustration depicts the real-time EMG activity displayed to the user.

It is important to note that there is overlap and ambiguity between the definitions of biofeedback and biofeedback training. After a thorough review of existing literature, it became apparent that there are blurry boundaries between these two terms and discrepancies in their usage. It was common practice for researchers to employ biofeedback systems where participants could not interact or engage with the display; an example is a study by Dvořák et al., 2016.

A distinction is made in this research trial that biofeedback using EMG sensors will involve the biofeedback training of the operator.

2.4.1 Biofeedback training applications

Biofeedback training has a wide range of applications with numerous studies. Typical applications are in treating stress, anxiety and depression (Thabrew et al., 2018). Another popular application for biofeedback has been to enhance the performance of musicians and athletes (Deschodt Arsac et al., 2018). Biofeedback has also been widely used in rehabilitation research (Bowman et al., 2021).

Despite numerous studies the effectiveness of EMG biofeedback training in the literature remains inconclusive. In their study, Xie et al. (2021) reported that EMG-biofeedback training was found to improve knee range of motion in patients after knee surgery. In contrast, Kamonseki et al. (2021) found no significant effect when EMG biofeedback interventions were used to improve the pain and function of patients with shoulder pain. Bowman et al. (2021) conducted a review to explore the application of wearable sensor biofeedback in rehabilitation, its most common application. This study examined nineteen randomised controlled trials, with a particular emphasis on Parkinsons disease (6 trials), stroke patients (13 trials) and individuals with mild cognitive impairment (1 trial). Drawing conclusions proved difficult for the authors but they did report positive effects from the trials.

Research using biofeedback training is becoming more common with more promising results being reported. Morales-Sánchez et al. (2022) used biofeedback training for neuromuscular rehabilitation in soccer players. The authors emphasised the value of incorporating this method and proposed incorporating this technique alongside other orthopaedic rehabilitation interventions may enhance the chances of athletes' recovery. Improvements were observed during the biofeedback intervention, as evident from the differences between the pre- and post-intervention trials. This finding suggests that the procedure facilitates muscle memory, enabling the muscle to function more efficiently. These improvements and the longevity of these effects are still unclear but there has been research conducted which have reported sustained improvements. In their study, Criado et al. (2016) reported that EMG-biofeedback training reduced EMG activity in the muscles they recorded. This decrease in activity was recorded to have continued following the end of the training session. Furthermore, all patients experienced a decrease in painful symptoms in the areas of the recorded muscles.

These systems can be successfully utilised in more challenging and dangerous environments. In a study conducted by Sokoler and Bagalkot (2017), they examined the use of a bar display with LED lights to help motorbike riders maintain spinal alignment. The aim was to encourage riders to make adjustments while riding, reducing the chances of lower back injuries. Encouragingly the participants provided feedback indicating promising results from this intervention.

2.4.2 Biofeedback training in forestry

The utilisation of this specific training technique for the purpose of physiological improvements holds significant promise. There is a lack of literature that specifically examines the application of EMG sensors together with biofeedback training in harvesting operations. There was only one study that was found that used this training system on forestry operators, but the findings were inconclusive. Parker and Wright (1999) implemented EMG biofeedback training on harvesting machine operators as part of a pilot trial aimed at exploring the potential use of EMG and biofeedback technology in forestry operations. The biofeedback training system utilised an array of LED lights, whereby the operator was required to maintain a green light by consciously relaxing their shoulders. The effect was found to be minimal for one operator, while the other experienced a temporary effect. Nevertheless, this study highlighted the potential benefits and indicated the usability associated with integrating EMG Biofeedback training systems into machine operators' cabs.

2.5 Discussion and conclusion

EMG has been effectively utilised in numerous studies across various fields. Within the literature, numerous studies have been conducted using EMG sensors on individuals operating forest machinery. Upon reviewing the available literature, it became evident that there has been an increase in popularity associated with biofeedback training, yielding more favourable outcomes. More research is still required to evaluate the effectiveness of biofeedback training. This research aims to contribute towards the growing literature using biofeedback training.

Challenges and difficulties associated with using EMG biofeedback systems inside forestry cabs were mentioned in the literature. As an initial step towards this research aim, it is imperative to conduct a pilot trial to assess the usability and investigate the practicalities of using this training system on machine operators.

Chapter 3 Pilot Trial

This chapter details the initial steps taken to start using an EMG biofeedback training system in a harvesting operation. The following chapter includes an introduction, methods, results, results discussion section, recommendations, and a conclusion. The findings from this trial informed the requirements and selection criteria for equipment and testing methodology employed in the larger trial.

3.1 Introduction

The wearable technology market is experiencing continuous growth, with an increasing number of products being introduced. Despite this growth, the reliability of these products for research purposes is questionable due to the lack of independent testing (Peake et al., 2018). High-end biofeedback systems, such as ADInstruments - Trigno system, Biopac - MP160 system, Schuhfried - Biofeedback 2000x-pert, and BTS Bioengineering – BTS FREEEMG, come at significant costs ranging from thousands to tens of thousands. Hence, before making an investment in this technology, it becomes imperative to assess its performance.

To begin using an EMG biofeedback system effectively for research purposes or training sessions alike requires careful selection. The market is flooded with a variety of EMG capable sensors; thus, it becomes crucial to evaluate whether a biofeedback training system would be suitable before committing resources. In order for the EMG biofeedback system to function optimally during the primary research trial, it is necessary to establish a set of requirements that must be met.

3.2 Aim

The main objective of this initial trial was to assess how effective the Resility Wireless EMG Biofeedback Sensor is and determine if it meets the requirements for future research. Our aim was to thoroughly evaluate the Resility Wireless EMG Biofeedback system and provide a comprehensive list of recommendations and justifications that

can be used to acquire a more advanced EMG biofeedback system. Even though McKain (2019) briefly mentions the Resility EMG system in their book, there is limited existing literature from other researchers. It is worth noting that the Resility sensor has not been independently verified and is primarily considered an additional tool for enhancing stress resilience (Resility, n.d.). This trial will evaluate how well the Resility Wireless EMG Biofeedback system performs in a machine cab and an office setting for reference. This trial was used to identify any limitations that would help support the decision to invest in a more expensive system for the primary research trial.

3.3 Methods

This section explains the methodology employed during the pilot trial to evaluate the usability of the chosen biofeedback system in a working forestry machine. The primary objective was to evaluate how well the sensor performed on a machine operator and compare it to an office worker's experience, which served as a reference point for comparison.

3.3.1 Ethical considerations

Confidentiality was a critical consideration while collecting recordings from the selected forestry operator. Steps were taken to avoid identifying information and images were blurred as necessary.

3.3.2 Equipment

This research focused on utilising non-invasive electrodes, specifically surface electromyography (EMG) for its intended objectives. The following section details the equipment used during the pilot trial.

3.3.2.1 EMG biofeedback system selection for the pilot trial

The Resility Bluetooth EMG Muscle Activity Sensor system was selected for this initial trial. The Resility Bluetooth EMG Muscle Activity Sensor system is lightweight, weighing just 25g and measuring 72 mm x 29 mm x 12 mm. It works seamlessly with both iOS and Android devices, connecting via Bluetooth. What sets it apart is the threshold alarm feature, which provided visual or auditory feedback alerts, allowing for

biofeedback capability. Resility offered an affordable option at \$250 USD. It is also portable, allowing the operator to easily interact with the display to fulfil the objectives of this trial. Considering all these factors, Resility emerged as the ideal choice to explore the potential of biofeedback training within a forest machine cab.

3.3.2.2 Materials

High-quality surface electrodes were used to ensure accurate readings. Specifically, the Covidien Kendall Disposable Surface EMG/ECG/EKG Electrodes measuring 1 3/8" (35mm) were utilised. These disposable electrodes have compatible snap connectors with a pre-gelled adhesive side, making them easy to use.

During the biofeedback training it was necessary to have a method to fix the biofeedback display in the machine operator's cab. A generic phone stand was chosen. This ensured the operator could easily monitor their muscle activity and make necessary adjustments. This stand was also required for safety purposes.

3.3.3 Experimental design

3.3.3.1 Electrode placement

The primary focus of this study is on the trapezius muscle due to its suspected involvement in work-related musculoskeletal disorders (Cescon et al., 2008). Following the guidelines provided by Resility, the testing site was prepared using alcohol wipes to clean the target areas before applying the electrodes. The Resility EMG sensor and adhesive snap-on electrodes were then affixed to the upper trapezius muscle of the participants, who were either sitting or standing in a relaxed position. The right-hand side upper trapezius muscle was recorded for the office worker and machine operator. Resility Health offers recommendations on the placement of electrodes on the upper trapezius muscle. The Resility user guide mentions a book by Preston and Shapiro (2020) as a reference, but no citations are included in the guide itself. Furthermore, the guide does not provide any instructions regarding a calibration procedure.

3.3.3.2 Biofeedback display

The Resility system was equipped with a biofeedback display. The app was operated on an iOS device connected via Bluetooth. The biofeedback display had various features such as recording time, a circle with running bars displaying the current EMG signal with the threshold alarm setting, an oscilloscope, and an alarm threshold slide bar. An alarm (sound and vibration) was configured to notify the operator when they exceeded the set threshold. This alarm threshold was set halfway during the training.

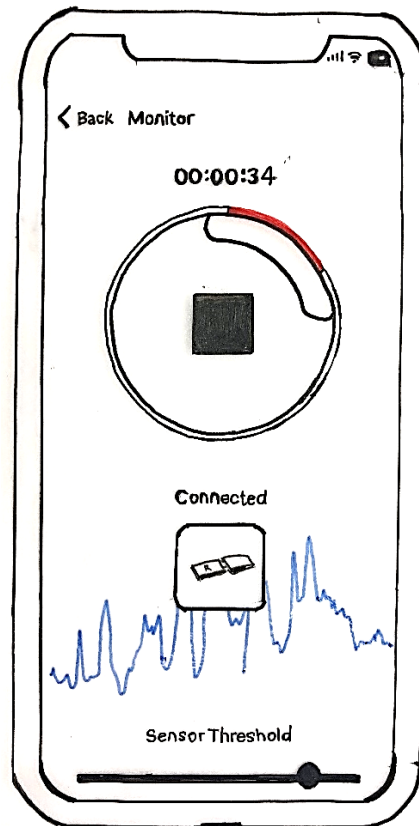


Figure 6 Resility Wireless EMG Biofeedback mobile app display

The illustration shows the Resility app biofeedback display. The screen displays the recording time, the EMG signal on an oscilloscope (depicted in blue) and slide bar to set the threshold for the feedback alarm (bottom of the screen). The threshold setting is displayed as the red outer circle and the user's current EMG signal is displayed on the inside of the circle.

The biofeedback display and stand were in a location of the operator's choosing. The operator could easily monitor their muscle activity and make necessary adjustments.

3.3.3.3 Locations

The office-based participant was located in the Scion Christchurch offices.

The selected ground-based harvesting crew was located near Christchurch. The selected participant was operating a CAT logging machine equipped with a grapple, also called a loader. Testing was conducted with the assistance of a representative from Rayonier Matariki Forests.

3.3.3.4 Participants

The experiment involved testing one person in a controlled office environment and one in a working forestry machine. An office-based Scion (New Zealand Forestry Research Institute Limited) employee volunteered to participate in the pilot trial. The office-based participant was female in the 30-40 age bracket. One machine operator volunteered to participate in the pilot trial. The participant was male in a 30-50 age bracket. Both participants mentioned that they were in good health and had not experienced any recent upper body injuries or discomfort in the neck and shoulders. The collection of weight and height data was not conducted.

3.3.3.5 Testing protocol

The pilot trial involved the assessment of the Resility system on an office worker and a machine operator. In the office, the participant performed typing tasks using a computer station setup, while on the landing, the machine operator operated sorted and fletted logs in a loader. In the office, the biofeedback display was placed in a visible location on the worker's desk, while in the forestry machine cab, it was fixed to the glass in a visible location that would not disrupt the workflow.

Data was collected using the Resility Wireless EMG Biofeedback Activity Sensor for approximately 10 minutes while participants completed their tasks. The recording was initiated through the app display, and a timer indicated that the recording had started. During testing, the participants were to engage with biofeedback display and participate in the training element which was conscious relaxation. Specifically, by using the app screen for reference the participants were instructed to keep their current EMG signal activity as low as they could during their task. The current muscle activity is represented as a moving bar inside the circle (Figure 6).

After completing the recordings, Participants were asked to provide subjective feedback through an informal verbal survey.

3.3.3.6 Data analysis

The evaluation of the Resility system included participant experience, usability, and result analysis. Recorded sessions were downloaded via the XenApp login on the Resility website. Data is presented in charts for straightforward interpretation.

3.4 Results

3.4.1 Office-based worker results

An EMG recording lasting approximately 10 minutes (626 seconds) was obtained during this trial. This recording displayed a fluctuating muscle activity range of 1 to 1.8 μV (Figure 7). The participant provided feedback stating that the device was comfortable to wear and that the screen was easily visible. The participant reported actively trying to relax their muscles while the biofeedback EMG running circle was displayed on the screen. The recording shows three peaks, which can be attributed to the participant's intentional and acknowledged efforts to surpass the predefined threshold due to their curiosity; the alarm could be heard on three separate occasions.

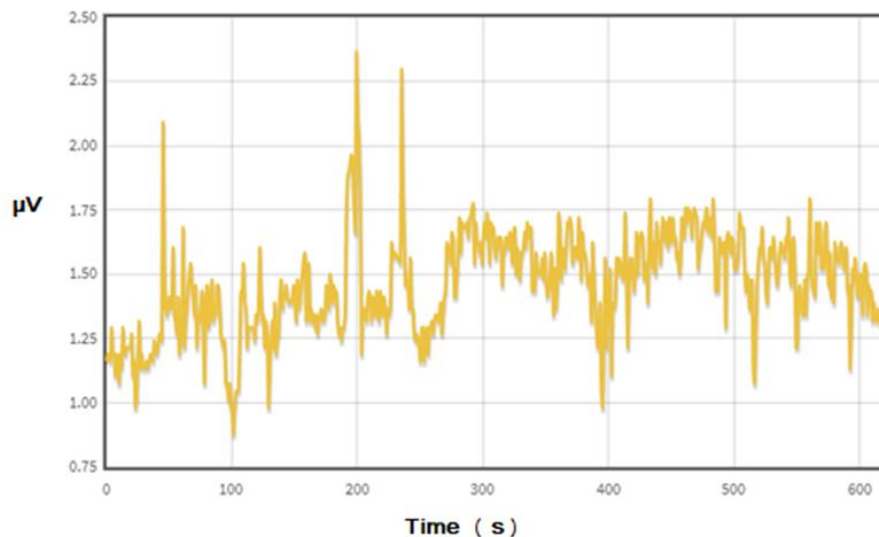


Figure 7 Office participant EMG recording

Office participant EMG muscle activity recording. Unit: Microvolts (μV), Seconds (s).

No further analysis was possible; this is discussed in the Results discussion section.

In conclusion, the office-based participant activity engaged with the biofeedback display and consciously relaxed their muscles throughout the biofeedback training trial.

3.4.2 Forestry operator results

The Resility system failed to transmit the recorded EMG signal data to the Xen platform. This is discussed in the Results discussion section. Despite this setback, the operator could view the current EMG signal displayed during the trial and could still participate in the biofeedback training trial. Therefore, the operator's experience and feedback were collected. The operator noted that the screen's visibility and cluttered visual setup were problematic. This observation is crucial as it suggests the importance of using an appropriately sized device and a more uncomplicated display when using biofeedback training in machines. Furthermore, the operator reported that the noise in the machine cab made it almost impossible to hear the threshold alarm.

3.5 Results and discussion

3.5.1 Findings

An assessment was conducted on the Resility Wireless EMG Biofeedback Activity sensor system. The Resility EMG sensor was considered unsuitable for the primary and any future research trials for several critical reasons. These reasons are further explained in this section.

The Resility sensor lacks onboard memory storage so the recording of the machine operator was lost. This is speculated to be due to connection issues. The lack of onboard memory on the sensor presents a significant drawback. This means that if the connection is compromised, there is a high risk of complete data loss. As a result, this sensor was deemed unreliable.

Another drawback of the Resility system is the lack of disclosure from the company around the electrical and technical specifications. Resility Health failed to respond to all queries regarding the specifics of the Resility EMG sensor circuitry, signal acquisition and preamplification settings. Without this information the accuracy or

reliability of the data produced by the device could not be determined. Any filtering or pre- and post-processing of the data is also not disclosed.

The lack of freely accessible data poses a significant drawback, as it restricts data analysis and results. Metadata and graphs from the pilot trial were available, but access to the raw data was not possible. This is what occurred during the office-based workers' trial, and no data analysis was possible.

The biofeedback display was poorly designed when used in a forestry cab. The display hindered the machine operator's ability to interpret the biofeedback display accurately as it was too small and too cluttered with features. This issue compromised the biofeedback training as the operator was not able to engage with the screen effectively.

The absence of customer support adds to the sensor's unsuitability, leaving users without guidance or assistance in technical difficulties or inquiries. Despite repeated attempts to contact Resility Health's customer service, no response was received.

Considering these critical reasons, it is concluded that the Resility EMG system is unsuitable for the primary research trial and any future research using EMG biofeedback.

On a more positive note, the sensor incorporated in the Resility EMG system was lightweight and easy to install. The Resility Wireless EMG Biofeedback Activity Sensor system functioned effectively in an office environment but did not meet the requirements for a real-life forestry operation.

It is worth acknowledging that the utilisation of EMG biofeedback systems in harvesting operations presents a notable challenge. The considerable size of these forestry machines presented difficulties in terms of accessibility and installation, particularly with regard to integrating the biofeedback display into the cabin (Figure 8).



Figure 8 Biofeedback display installation

The image shows a forestry machine used in the study and illustrates the difficulty of accessing the cab and operator.

3.5.2 Recommendations

To ensure the collection of optimal EMG signal recordings and to achieve the aims of this research, the following key recommendations have been carefully complied with to ensure desired outcomes:

1. Storage: To address potential challenges associated with poor communication in the forestry cab and operators moving out of range, an onboard memory system (solid state memory) is recommended. This will effectively eliminate any data gaps or "holes" that may occur, ensuring a seamless and uninterrupted data flow in a machine cab.
2. Wireless EMG sensors: Wireless EMG systems offer numerous advantages, including enhanced mobility, flexibility, and ease of use, thereby significantly improving the overall user experience and allowing users to move freely without being constrained by cables or wires. A wireless system would also shorten participant setup time, reducing productivity disruption.

3. Lightweight electrodes: Lightweight sensors are recommended to minimise any undesirable artefacts in the EMG signal and for the operator's comfort. This will ensure accurate movement detection from the participant and not disturb or distract the operator while working.

4. Customisable biofeedback display: The ability to alter the biofeedback display can significantly enhance their overall engagement and understanding of the data. By allowing users to personalise the display according to their preferences, the project can facilitate a more tailored and interactive experience, ultimately leading to more favourable outcomes.

5. Ongoing product and technical support: It is essential to select an EMG system with good technical support to ensure timely assistance and guidance, addressing any issues or concerns that may arise during the implementation and utilisation of the system.

3.6 Conclusion

The selected EMG biofeedback system will be required to follow the recommendations highlighted in this pilot trial to ensure improved functionality, seamless communication, enhanced user experience and technical support. With these recommendations, this research will be conducted using a well-equipped and reliable system.

One significant observation derived from carrying out this pilot trial was the crucial role played by equipment selection in the success of a research trial. The majority of products available on the market lack independent testing and validation, rendering them unreliable for research purposes (Peake et al., 2018). Proceeding to the primary trial with the Resility Wireless EMG Biofeedback Sensor without proper evaluation could have resulted in serious consequences for the accuracy and reliability of results. The main lesson learned here is the significance of selecting appropriate, validated, specifically designed equipment for the intended purpose.

Note: Following writing this thesis, the Resility Health website is no longer available (active during 2017 – 2022). Alternative information about this inactive website can be found on archive.org/web/. The URL can be found under Resility in References.

Chapter 4 Methods

The following chapter provides a detailed overview of the approach utilised in the primary field trial. This chapter explains various aspects and details of the chosen EMG biofeedback system, experimental design, and data processing and analysis. The chapter aimed to offer a thorough understanding of the methodology adopted to investigate the effectiveness of the EMG biofeedback system on forestry machine operators.

4.1 Ethical Considerations

As this research involved participants the University of Waikato required the approval from a committee delegated from the University Human Research Ethics Committee before the study could commence. Formal approval was granted. See Appendix B Ethics approval document.

4.2 Equipment

This research will focus on the utilisation of non-invasive electrodes, specifically surface electromyography (EMG), for its intended objectives.

4.2.1 EMG biofeedback system selection

The BTS FREEEMG 1000 system from BTS Bioengineering in Milan, Italy, was selected for the trial. This system choice was made based on the recommendations mentioned in Chapter 3. The BTS FREEEMG 1000 package offers various features such as real-time biofeedback, wireless and surface EMG sensors, a user-friendly software interface, and validated functional test protocols. The extended 20m signal range of the sensors makes them well-suited for this research trial, and they have excellent signal accuracy at 1KHz. These sensors have a sensitivity range of 1 μ V to 6mV and a performance accuracy of \pm 2%. The sensors can record continuously for up to 8 hours and are lightweight, weighing only 13 grams. Each sensor comprises a mother electrode and satellite electrode connected via a flexible cable to ensure viable geometry. One key factor in choosing this system is that the sensors have 2 hours of

internal memory storage due to an onboard solid-state buffer memory system. The package also includes the BTS EMG-Analyzer software application for EMG signal analysis, and BTS Bioengineering technicians provide responsive technical assistance.

The BTS FREEEMG 1000 system, developed by BTS Bioengineering in Milan, Italy, is widely used for its high accuracy, precise time resolution, non-invasiveness, and portability (Artoni et al., 2018; Dhein et al., 2020; Jang et al., 2018). Although the system components of FREEEMG 1000 are not designed to resist liquid infiltration, there is an alternative option available known as the FREEEMG 1000 H2O system, which is specifically designed to be water and sweat proof. For future research requiring extended testing periods, it is recommended to explore using a liquid-resistant option.

4.2.2 EMGAnalyzer software

Experimental field measurements were aggregated using the EMG Analyzer software suite. The majority of the EMG signal power is concentrated between 10 and 250 Hz, and scientific recommendations advise setting the amplifier band between 10 and 500 Hz (BTS Bioengineering, n.d.). In line with the Sampling Theorem of Nyquist (Shannon, 1949), the sampling frequency was set to at least twice the signal bandwidth to prevent the loss of information. During the trial the EMG signals were acquired at a nominal sampling rate of 1000 Hz. The EMG channel range amplitude value was set to the default 3.0 mV range, which is suitable for most clinical and sports applications (BTS Bioengineering, n.d.). The default protocol was chosen for this research trial.

The technical specifications for the BTS FREEEMG 1000 system and relevant product information can be found in Appendix C BTS FREEEMG 1000 information.

4.3 Experimental design

4.3.1 Electrode placement

The primary focus of this study is the upper trapezius muscle. This muscle is extensively tested using EMG because it is stable, reliable, and known for its conductive qualities (Cescon et al., 2008). The upper trapezius muscle was selected as it has been subjected to extensive scrutiny owing to its association with work-related musculoskeletal disorders (Attebrant et al., 1997; Cescon et al., 2008; Veiersted et al., 2013). Two sensors were used to acquire the EMG signal of the trapezius muscle on the left and right sides of the operator. Electrodes were placed in a standardised location, between the acromion and C7 vertebra and 2 cm lateral of the midpoint, as depicted in Figure 9. Cescon et al. (2008) state that the innervation zone's location is approximately on the midpoint between the acromion and C7; they recommend collecting EMG signal recordings around the midpoint as the signals are stable and reliable with low impedance. The interelectrode distance and electrode placement technique were adhered to, with the electrodes being affixed parallel to the muscle fibres, specifically at a distance of 2.0 cm (Farina et al., 2002).

Before installing the electrodes, the skin was prepared to optimise the quality of EMG recording. Recording sites were cleansed with alcohol (70% ethanol generic hand sanitiser) and dried before electrode placement. Electrodes were installed on participants while they were relaxed in sitting or standing positions. These measures were taken to decrease the impedance of the electrodes and guarantee uniformity among all the connections. Sensors (mother and satellite components) required snap-on electrodes to adhere and connect to the skin's surface. Adhesive hydrogel surface electrodes (35 mm teardrop-shaped Kendall™ 200 Foam Electrodes; Medtronic, Minneapolis, MN, USA) were used. These electrodes were pre-gelled, facilitating prompt patient preparation.

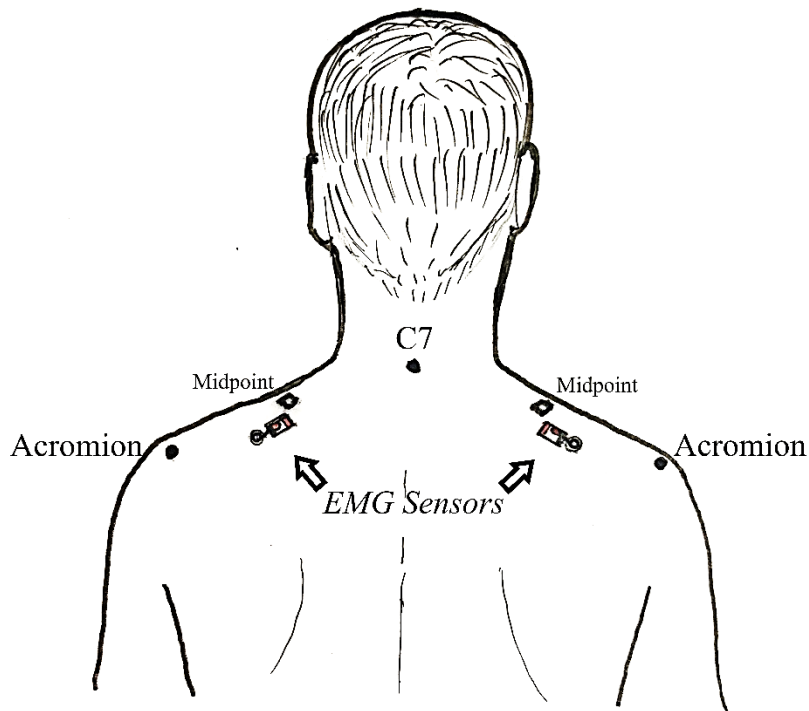


Figure 9 BTS FREEEMG 1000 sensor placement

Illustration depicts the location of the sensors placement while conducting EMG recordings.

This research trial involved collecting EMG signals of the upper trapezius muscle from both the left and right sides of the body. To account for variations in tasks performed by operators, on both sides were recorded to capture the intricacies and complexities of each task.

4.3.2 Biofeedback display

During the initial planning phase of this trial, crucial decisions were made regarding the biofeedback display. A biofeedback signal contains elements such as mode, content, frequency, and timing (Bowman et al., 2021). When determining appropriate elements and displays for this research trial, the concept of a traffic light design was proposed. The utilisation of a traffic light design was considered advantageous due to its familiarity as a well-known indicator for operators to interpret. Additionally, a traffic light design is considered simple and reduces the potential of distracting the operator were

seen as benefits. The operator would be instructed to "keep the light green as much as possible," serving as a training reinforcement to be followed during breaks or when the operator is not actively working. However, after extensive discussions with the software engineers at BTS Bioengineering, it was determined that developing a custom biofeedback display to meet these specifications within the study's timeframe would not be feasible. This aspect may be reconsidered in future research endeavours.

The EMG biofeedback display chosen for this research trial is the oscilloscope which displays the EMG signals for both the left and right sides (as shown in Figure 10). The reasons for this decision are included in Testing phases 4.3.3.



Figure 10 BTS FREEEMG 1000 biofeedback display

Image shows the location of the biofeedback display in a forestry cab. EMG signals of the left side are displayed on the top, while the right side is on the bottom.

4.3.3 Testing phases

Before implementing the BTS FREEEMG 1000 system in active forestry operations, it was crucial to conduct thorough testing. The testing process was divided into multiple phases to ensure the system's effectiveness and usability. Initially, the focus was on set up and using the sensors appropriately to collect accurate data. This phase occurred in an office environment, chosen for its controlled atmosphere. In the office

trial phase, the objective was to execute the installation and configuration of software, evaluate battery life, and assess the software's usability in terms of setting up patients and protocols. Queries were addressed regarding data storage and familiarisation was gained using the BTS FREEEMG 1000 system, with both the sensor and the EMG Analyzer software. This involved acquiring knowledge on accurately installing sensor electrodes by ensuring proper preparation and correct placement. Additionally, understanding how to operate the oscilloscope and biofeedback functions was crucial. Furthermore, learning how to initiate a trial run was also part of this process.

The second phase involved testing the system's remote capabilities inside a moving vehicle. This stage aimed to identify potential connection issues and determine if operators could effectively engage with the technology. An oscilloscope displayed the driver's EMG signals as biofeedback throughout this trial on a laptop. It was reported that this display did not divert the driver's attention and proved user-friendly and comprehensible. Consequently, it was determined that this display would effectively fulfil all essential elements required for a biofeedback interface during the research trial (Figure 10).

The third stage was carried out in an agricultural tractor, specifically to test the sensor and biofeedback display within the confines of a large and heavy machine. The primary purpose was to identify any challenges related to setup or usability that may arise in the cab of a forestry machine and resolve these before the field trial. Factors such as vibration were also considered and determining an ideal position for the biofeedback display was evaluated. It became evident during this phase that a display device smaller than a laptop would be necessary since there is insufficient space in the machine's cabin for such equipment (as can be seen in Figure 11). The EMG Analyzer software required a windows operating system; a Surface Pro 8 i7/16 GB RAM / 512GB SSD storage was acquired for the trial biofeedback display. A display stand was required for the surface computer, allowing it to be securely attached to a suitable location within the cabin where the operator could easily see it without obstructing their view or movement. An Arkon heavy-duty multi-angle tablet suction mount was selected to secure the display to the machine cab. These discoveries would have been unlikely if this tractor-testing phase was not conducted.

Conducting these comprehensive tests across different environments and scenarios ensured that any issues or limitations associated with deploying the BTS FREEEMG 1000 sensors on forestry operators would be identified and addressed effectively before implementation in real-life forestry operations.



Figure 11 Machine cab limitations

Image shows an operator's machine cab to show the space limitations when setting up a biofeedback display within the cab.

4.3.4 NASA TLX

The NASA Task Load Index, a widely referenced questionnaire, has garnered over 15,000 citations on Google Scholar since 1988 (Hart & Staveland, 1988). Users evaluate the level of demand associated with a specific task across six distinct dimensions, using a scale ranging from 1 (indicating low quality / good performance) to 20 (reflecting high quality / poor performance). NASA TLX is an effective tool for measuring perceived workload by breaking down operationalised workload into Mental Demands, Physical Demands, Temporal Demands, Frustration Levels, Effort Expended and Performance. This questionnaire was implemented to gauge differences in workload perception between control and biofeedback training. However, operators repeatedly encountered challenges completing the questionnaire due to differing interpretations of definitions while responding to the questions. This confusion was time consuming and a cause of frustration. Consequently, a decision was made to utilise the NASA TLX questionnaire only as a means for capturing

subjective data related to completed tasks and operated machinery. This subjective data was captured and integrated into the results discussion.

4.3.5 Locations

This research trial was conducted on operators in ground-based operations. This trial was spread among many crews in Canterbury and the West Coast. The participants were selected across the regions: eight crews (four in each region) of various sizes and systems (CTL and WT). Four field trips were conducted to complete data collection between June and August 2022. Harvesting extraction systems (CTL or WT) were not recorded. Crew names, exact locations, and forest names are not disclosed due to the risk to confidentiality when combined with experience and machine details.

4.3.6 Participants

Operators were pre-selected by a forestry contractor or a forest management company representative. Pre-selection was advantageous as those selecting the operators were familiar with them and could predict individuals keen to be involved. The potential participants were approached and given a concise overview of the study, including the requirements for their voluntary involvement. Individuals had the option to partake in the study willingly. Each participant received a trial information document and formal consent form, which were provided as preparation for the trial (refer to Appendix D Participant handouts for a copy of the Information Sheet and Consent Form). Queries raised by the participants were addressed throughout this process. This research trial recruited fourteen forestry machine operators to evaluate EMG signals (or muscle activity) during harvesting operations (Table 1).

4.3.6.1 Participant considerations

To maintain confidentiality and focus on the trial's objectives, specific details of the machines used are intentionally kept vague. The trial aims not to compare operators or tasks but to compare operator performance in two distinct phases: the control phase (without display) and the biofeedback training phase (with display available). While the exact number of years of experience is gathered, it is not explicitly mentioned in the table for privacy reasons. The question regarding experience is phrased as "How many

years have you been operating machinery?" It is important to consider that a response of less than one year may indicate a new starter in the forestry field with no prior experience, someone with experience in the recorded task but it was a long time ago, or an experienced logger who has recently started operating machinery. This question does not solely indicate the number of years spent in harvesting, as participants had lengthy careers in motor-manual felling and quality control before transitioning to operating machinery. This distinction is not explicitly stated in the data provided. Additionally, gender was not included as it has the potential to reveal the identity of participants. Although participant information was collected, it was not displayed in the table to protect their confidentiality, as it did not contribute any valuable insights. The operators were questioned about their health concerns and any injuries they may have had. It was found that all of them were able to operate the machines safely, and no issues regarding their ability to perform their tasks were reported. This topic will be elaborated upon in the Discussion chapter.

4.3.6.2 Machine operator descriptions

Table 1 Participant Details

Table details each operator participating in the research trial. Details include what machine they were operating and what task was conducted during the EMG biofeedback recording.

Operator	Machine type	Task	Experience (yrs.)
1	Loader	Loading Logging truck	25
2	Processor	Processing and fleeting	15
3	Loader	Loading Logging truck	5
4	Loader	Loading Logging truck	25
5	Processor	Processing on landing	25
6	Loader	Fleeting and sorting	30
7	Harvester	Felling	5
8	Loader	Fleeting and sorting	< 1
9	Processor	Processing and shovelling	20
10	Harvester	Felling and processing	10
11	Loader	Loading Logging truck	< 1
12	Loader	Loading Logging truck	< 1
13	Processor	Processing	10
14	Harvester	Felling and processing	10

Experience (yrs.) = years' experience as a machine operator

An additional illustration is located in Appendix E to visualise the general workflow and when each task occurs.

4.3.7 Experimental design

4.3.7.1 Initial design planning and executed design

The initial experimental design was restricted to participants performing sorting and fleeting tasks. This constraint aimed to minimise disruption and prevent any negative impact on operational productivity. Typically, these tasks were carried out using a loader stationed on a landing, ensuring easy access to the participants for setup. In the field it became crucial to implement a proactive and dynamic strategy and gather

data from any machine operators who showed willingness to participate. The absence of strict limitations allowed for adaptability and as a result a broad range of machines, variation of tasks, as well as operator experience levels were successfully captured. This research trial aimed to examine whether differences in muscle activity exist between control groups and those undergoing biofeedback training within forestry operations. Future research will establish specific parameters related to machine type, task requirements, and other relevant factors.

4.3.8 Testing protocol

The following figures describe the testing sequence conducted during this research trial.

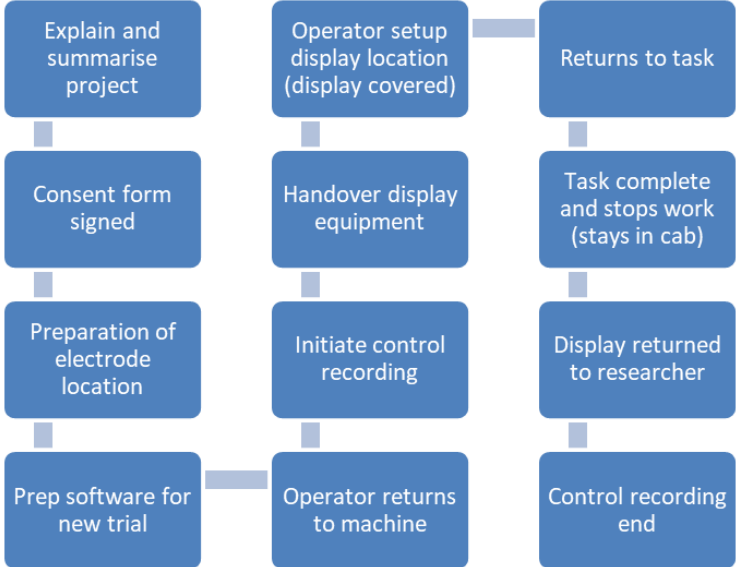


Figure 12 Control data collection process

The workflow during the control trial is depicted in the figure. Biofeedback testing commences immediately after the conclusion of the control trial.

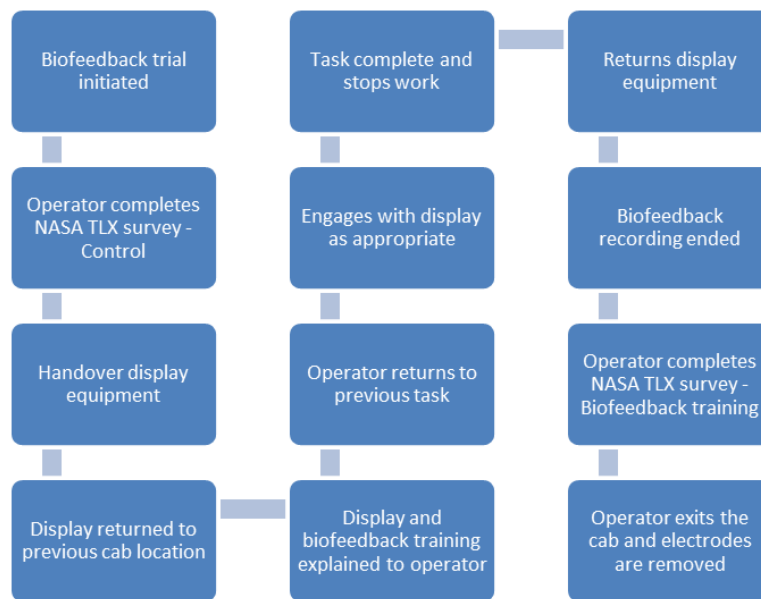


Figure 13 Biofeedback data collection process details workflow during the biofeedback trial

During the control measurements and biofeedback training, the operators were free to start and stop their tasks at their own pace. The experiment had an open-ended time limit to allow the operators to complete their tasks naturally without disrupting their workflow. The trial boundaries were set at a maximum of 10 minutes, with a delayed start of 2 minutes to stabilise the muscle activity and reduce the novelty effect. Research has shown that recordings exceeding 10 minutes can lead to distorted results due to the power spectrum of the signal frequency shift as fatigue increases (Veiersted et al., 2013). Sufficient pauses and breaks were incorporated before and following each treatment to ensure the accuracy of the measurements.

4.3.9 Data analysis

Initial measurements taken from the operator were considered a control, while biofeedback was implemented as the treatment. Using two-tailed paired *t*-tests the treatment and pre-treatment measurements were analysed to identify any potential differences. This trial's main objective was to determine if there were any notable differences between the control and biofeedback treatments.

4.3.10 Signal Processing

The approach for analysing EMG signals depends on the research question. This research provides an overview of the processing order, as depicted in Figure 14, which outlines the steps taken to analyse the raw signal data. An EMG activity analysis was performed using BTS Smart-Analyzer software, an extension software to the EMG Analyzer software. Prior to assessment, a thorough visual examination of the data was conducted to determine if it followed a normal distribution. The gathered data was organised and analysed, and the frequency domain was evaluated to examine the power spectrum. This was done through a Discrete Fourier transform (DFT) and Periodogram of Welch (PDW), used to visually confirm the normality of the distribution of frequency components in the signal and detect any noise or electrical artefacts that could impact signal quality. To improve the accuracy of peak and slope detection the signals were rectified and a root square mean (RMS) smoothing window of 50ms was applied to minimise the effects of noise. All recordings were normalised by time during processing, and each recording was compared based on 501 samples ($df = 500$). Graphs related to this analysis can be found in Appendix F Signal analysis of signal quality.



Figure 14 Signal analysis process

This figure details the process taken during EMG signal analysis.

Chapter 5 Results

An analysis was conducted on electromyographic data collected from thirteen machine operators. The participants, tasks, and machine details can be found in Table 1 in the previous Methods chapter. Operator 3 was excluded from signal processing and analyses due to file corruption issues, but subjective data was still retained for further discussion. During the control and biofeedback trials, recordings were made of both the upper left and right trapezius muscles. The data collection process is described in Figure 12 and Figure 13. Both sides of the body were analysed separately to evaluate any differences in muscle activity between control and biofeedback trials. These results provide valuable insights into the impact of biofeedback on muscle activity also known as electromyographic activity.

Statistical testing was performed using a paired two-tailed t -test to determine if there is a difference in the mean muscle activity of an operator using biofeedback training.

5.1.1 p value

The use of the p value in statistical analysis has been a topic of controversy and debate. Originally intended as a tool to determine further scrutiny of results, the p value has been misconstrued as a measure of scientific importance. Di Leo and Sardanelli (2020) suggest a conservative approach to reporting the p value as continuous quantities without claiming significance or non-significance. The p value does not provide the probability for the null hypothesis to be true but instead reflects the compatibility of the data with the null hypothesis. The American Statistical Association (ASA) warns against the misuse of statistical significance and p values (Di Leo & Sardanelli, 2020; Wasserstein & Lazar, 2016). They emphasise that statistical significance does not guarantee the existence or absence of an association or effect and caution against making judgments solely based on statistical significance.

Furthermore, Wasserstein et al. (2019) advise against using confidence intervals as another means of dichotomization. This study will use the p value as a guide to assess the evidence against the null hypothesis, with a threshold value of 0.05. If future research produces substantial p values, it can be inferred that the observed outcomes are not simply a result of random chance. The results section of this study will declare exact p values above 0.001 without indicating significance or non-significance.

5.2 Left side results

The paired two-tailed *t*-tests showed a difference in the means of muscle activity between control and biofeedback training. Table 2 shows the descriptive statistics (mean, standard deviation, difference between control and biofeedback, the standard error of the difference, *t*-test, and *p* value) for the muscle activity measurements for control and biofeedback trials. Operators 1, 2, 4, 5, 6, 7, 8, 10, 11, 12, 13 and 14 had a reduction in muscle activity means during biofeedback training (2.14, 5.63, 14.32, 2.59, 10.13, 3.49, 12.74, 8.94, 0.65, 34.41, 4.01, 7.18 μ V, respectively).

Operators 2, 4, 5, 6, 8, 9, 12 and 14 had *p* values <0.001 (t: 3.89, 7.27, 4.63, 7.64, 7.74, 10.31, 11.04, 3.81, respectively). Operators 7, 10 and 13 had *p* values of <0.05 (t: 2.01 *p*: .043, t: 3.22 *p*: .001, t: 2.01 *p*: .045, respectively).

Results of the *t*-tests show a difference in muscle activity means between the control and biofeedback training recordings.

Operators 1 and 11 had *p* values > 0.05 (t: 1.93 *p*: .054, t: 0.26, *p*: .798, respectively), as shown in Table 2. The muscle activity mean increased during the biofeedback (5.72 μ V) trial for operator 9, as stated in Table 2.

Results indicate that the majority of operators recorded a difference and for most a decrease in muscle activity on the left trapezius muscle during biofeedback training.

Results indicate an incompatibility with the null hypothesis (H_0): EMG biofeedback training does not affect muscle activity.

Table 2 Left side results

Descriptive characteristics and statistics for control and biofeedback recordings of the left trapezius muscle during work. Results per operator: mean, standard deviation, mean difference, standard error of difference, *t*-test, and *p* value. Electromyographic activity (muscle activity) is expressed in microvolts (μV).

Electromyographic activity μV								
Operator ID	Control		Biofeedback		Difference	Difference SE	<i>t</i> -test	<i>p</i> value
Left	<i>M</i>	SD	<i>M</i>	SD	(C-BF)			
1	43.40	17.94	41.26	15.4	2.14	1.11	1.93	.054
2	33.93	32.65	28.31	15	5.63	1.446	3.89	.0001
4	47.53	39.11	33.22	15.52	14.32	1.969	7.27	.0001
5	17.88	9.66	15.29	8.33	2.59	0.559	4.63	.0001
6	25.85	25.19	15.72	12.2	10.13	1.325	7.64	.0001
7	37.87	33.19	34.38	18.62	3.49	1.74	2.01	.045
8	55.36	29.02	42.62	16.93	12.74	1.646	7.74	.0001
9	20.87	9.23	26.60	9.52	-5.72	0.555	10.31	.0001
10	86.13	49.89	77.19	38.67	8.94	2.777	3.22	.0014
11	44.67	51.21	44.02	25.1	0.65	2.548	0.26	.798
12	77.06	68.25	42.64	21.98	34.41	3.118	11.04	.0001
13	52.05	37.57	48.04	22.95	4.01	1.997	2.01	.045
14	47.84	31.72	40.66	27.06	7.18	1.886	3.81	.0002

Note: *M* = mean, SD = standard deviation, SE = standard error; μV = microvolts. C = control, BF = biofeedback. $\alpha \leq 0.05$. Temporal normalisation: df = 500

5.3 Right side results

Results of the paired two-tailed *t*-tests showed a difference in the means of muscle activity between control and biofeedback training. Table 3 shows the descriptive statistics (mean, standard deviation, difference between control and biofeedback, the standard error of the difference, *t*-test, and *p* value) for the muscle activity measurements for control and biofeedback trials. Operators 1, 2, 4, 5, 6, 7, 8, 9, 10, 11, 12 and 14 had a reduction in muscle activity means during biofeedback training (4.25, 3.9, 0.02, 3.95, 2.04, 19.09, 14.5, 16.82, 7.83, 7.83, 89.41, 7.52, 7.40 μV , respectively).

Operators 2, 5, 7, 8, 9, 11 and 14 had *p* values < 0.001 (*t*: 3.93, 5.82, 7.09, 5.32, 11.51, 20.95, 4.04, respectively). Operators 1, 6, 10 and 12 had *p* values < 0.05 (*t*: 2.11 *p*: .035, *t*: 2.99 *p*: .003, *t*: 2.36 *p*: .019, *t*: 2.71 *p*: .007, respectively). Results of the *t*-tests show a notable difference in muscle activity means between the control and biofeedback training recordings on the right side.

Results of the *t*-tests show a difference in muscle activity means between the control and biofeedback training recordings. Operators 4 and 13 had *p* values > 0.05 (*t*: 0.01 *p*: .99, *t*: 1.01 *p*: .06, respectively), as stated in Table 3. Operator 13 increased muscle activity during biofeedback (2.13 μV), as shown in Table 3.

Results indicate that the majority of operators recorded a difference and for most a decrease in muscle activity on the right trapezius muscle during biofeedback training. Results indicate an incompatibility with the null hypothesis (H_0): EMG biofeedback training does not affect muscle activity.

Table 3 Right side results

Descriptive characteristics and statistics for control and biofeedback recordings of the right trapezius muscle during work. Results per operator: mean, standard deviation, mean difference, standard error of difference, *t*-test, and *p* value. Electromyographic activity is expressed in microvolts (μV).

Electromyographic activity μV								
Operator ID	Control		Biofeedback		Difference (C-BF)	Difference SE	<i>t</i> -test	<i>p</i> value
	<i>M</i>	SD	<i>M</i>	SD				
1	64.80	33.45	60.55	33.14	4.25	2.014	2.11	.035
2	33.80	20.66	29.91	14	3.90	0.993	3.93	.000
4	39.70	24.78	39.69	16.12	0.02	1.283	0.01	.990
5	22.05	10.94	18.10	9.77	3.95	0.678	5.82	.000
6	17.13	13.28	15.09	8.87	2.04	0.682	2.99	.003
7	56.71	51.84	37.62	20.2	19.09	2.691	7.09	.000
8	84.27	57.58	69.78	24.89	14.50	2.726	5.32	.000
9	37.52	34.1	20.70	10.6	16.82	1.461	11.51	.000
10	74.97	51.09	67.14	46.79	7.83	3.315	2.36	.019
11	118.52	90.02	29.11	18.38	89.41	4.269	20.95	.000
12	72.37	55.57	64.85	26.48	7.52	2.779	2.71	.007
13	80.66	33.53	82.79	33.15	-2.13	2.105	1.01	.311
14	36.83	29.81	29.44	28.3	7.40	1.831	4.04	.000

Note: *M* = mean, SD = standard deviation, SE = standard error; μV = microvolts. C = control, BF = biofeedback. $\alpha \leq 0.05$. Temporal normalisation: df = 500

Chapter 6 Discussion

The main objective of this research was to explore the effectiveness and applicability of EMG biofeedback training on machine operators. The study utilised the BTS FREEEMG 1000 system (BTS Bioengineering, Milan, Italy) to capture and present the operator's EMG signal. The operators were encouraged to monitor the display and consciously relax their muscles to minimise the EMG signal on the oscilloscope to zero. The experimental design aimed to capture any potential differences that could be achieved through this training tool. The results indicated a decrease in muscle activity among most operators on at least one side of their bodies.

The upcoming sections will discuss the results, the trial, and future research possibilities. The strengths and limitations of the technology will be covered, followed by a reflection on the research.

6.1 Results discussion

The following section examines the results and evaluation of the research experiment.

The findings suggest that most operators had a noticeable difference in average muscle activity between the control and biofeedback training recordings. Upon analysing the results, it became evident that biofeedback had an impact on muscle activity. Overall, the average muscle activity for most operators decreased during the biofeedback training. Specifically, out of the 13 *t*-tests conducted on the left trapezius muscle, 10 displayed a decrease in muscle activity. Similarly, 11 out of the 13 *t*-tests indicated a reduction in muscle activity in the right trapezius muscle. These findings suggest that biofeedback holds significant potential for reducing muscle activity in forestry operators. However, further examination is required, as indicated by the resulting *p* values, and additional trials should be conducted.

Results indicated that a small number of operators had no notable difference in mean muscle activity between trials and a small number displayed increased muscle activity during biofeedback. Further explanation of the probable causes for this is speculated in the next sections. Operator 1's results did not show adequate differences on the left side when comparing control and biofeedback trials. The obtained p value was greater than 0.05 (t : 1.93 p : .054), as reported in Table 2. The operator's subjective data revealed that the biofeedback trial posed greater challenges during loading. Specifically, the operator reported that loading the specific grade of wood (chip) usually proved to be more difficult due to the size of the wood and the complexity of loading small wood into the log truck packet, as compared to loading in the control trial. Additionally, loading a log truck with a loader may require different lever or joystick inputs, as described in the Introduction chapter. Operator 11 was also loading a logging truck during recording and had little recorded difference in muscle activity mean (t : 0.26, p : .798) on the left side. This result could also be due to the low utilisation of the left trapezius muscle, as the task requires more of the right-hand lever. Operator 9 recorded increased muscle activity on the left side during biofeedback training (5.72 μ V) (Table 2). According to the operator the tasks had changed between the trials; during the control trial they were performing processing and during biofeedback training they were shovelling logs. This change of task possibly explains the results.

On the right side, operators 4 and 13 had p values > 0.05 (t : 0.01 p : .99, t : 1.01 p : .06, respectively) (Table 3), indicating little difference between control and biofeedback training. Operator 4 was loading a logging truck during the trial. They had disclosed serious health issues and injuries which could explain their results. Operator 13 was processing during the trial which can require heavier input on the left-hand lever. This may have affected the results and explains the increased muscle activity on the right-hand side during biofeedback (2.13 μ V). Operator 11 measured a large decrease (t : 20.95, p : $< .001$) of 89.41 μ V (control, biofeedback: 118.52 ± 90.02 , 29.11 ± 18.38 μ V, respectively) as shown in Table 3. This could be due to an extended novelty effect or due to the operator's experience in the task, as this operator was a novice with <1 year experience.

Overall, the results from both sides indicate an incompatibility with the null hypothesis (H_0): EMG biofeedback training does not affect muscle activity.

This research received positive feedback during the trials. Most operators were keen to participate and discuss their work and saw value in the research aim. Very few of the 14 participants were hesitant or unmotivated to engage with this technology. It is noted that two operators were hesitant during the setup phase of the trial; acceptance of new technology in an already technology heavy environment was speculated to be the cause. A possible concern for these hesitant operators was the perceived difficulty of the task being asked of them, i.e., engaging with the biofeedback display for training. Following trial completion, both operators were optimistic about their experience with the biofeedback training. Operators found the EMG signals on the oscilloscope easy to interpret interesting enough to maintain interest and most treated the biofeedback training like a game, as seen in Figure 15. One operator enjoyed using the biofeedback tool so much that they saw enough benefit to suggest integration onto the machine's control panel.



Figure 15 EMG signals on biofeedback display.

The image shows that the real-time waveform on the oscilloscope was easy to interpret and interesting enough to maintain interest.

6.2 Trial discussion

This section discusses the complexities of the research trial, its limitations, and noteworthy observations.

This research builds on the foundation of other research using EMG sensors in the forest industry (Gellerstedt, 1997; Jankovský et al., 2018; Macků & Dvořák, 2013; Natov et al., 2016; Škvor et al., 2023; Škvor et al., 2022). The objective of this research study was effectively achieved by implementing an EMG sensor system and biofeedback training for machine operators. The findings present a functional biofeedback training system within the context of a forestry machine, with data collected from 13 operators.

Conducting trials on operators in harvesting operations presents a unique challenge due to the dynamic nature of their work. Operators must constantly adapt as they go, complicating field testing. Factors such as log trucks coming and going and the need for changing tasks all being exacerbated by time pressure add to the complexity of harvesting operations which meant it was critical to collect subjective data for reconciliation and explanation of results. Another challenging aspect of this research trial was using the EMG biofeedback training system while operators felt production pressure. Production pressure was a critical factor that limited setup procedures, trial design, and duration. The trial design and duration restricted how much preparation was feasible for the recording sites on the operators. For example, one of the most important steps in optimising the quality of the EMG recording is preparing the skin surface before electrode placement. This preparation typically requires hair removal, light abrasion using an exfoliating tool and cleansing of the electrode site with alcohol (Xie et al., 2023). Under the time pressure only the alcohol cleanse was conducted due to impracticalities and to maintain the operators' comfort. This production pressure was managed by implementing an efficient data collection process (Figure 12 and Figure 13) and maintaining awareness of production pressures, and the operators were able to maintain a positive attitude and actively participate throughout the trial. As the aim of this research was to record muscle activity and assess the existence of differences when using biofeedback training this required a total commitment from the operators.

Results entirely relied on the operators engaging with the biofeedback display which was a variable and uncontrollable element and the operator needed to accede and put in effort. Ergonomic interventions can be seen as a chore and an existing stigma of uselessness and a waste of time which could jeopardise this research trial's results (McLean & Rickards, 1998).

A discussion point for future research was an observation made during fieldwork was the overall lack of knowledge and importance placed on the correct ergonomic settings while working. The more experienced operators appeared more aware of the risks of WRMSDs. These experienced operators also tended to have a primary machine which they could personalise. This was a concerning observation for the less experienced and transitory operators as due to the nature of their work, these operators are at a higher risk of developing these disorders. It can take time and knowledge to set up a seat and armrests correctly and this set-up is not feasible when the machine is communal. Another challenge was that device installation in the forestry cab was difficult as most cab specifications were different in each machine which caused unexpected delays. The trial included many different machine manufacturers and machine ages which explained the variability. Access to the operator and setting up the biofeedback display in the machine cab posed challenges due to the size of the machine.

No prerequisites for participant selection were made as one of the research goals was to gather data from forestry operators without bias. This approach is not typical for research using EMG sensors as subjects are typically required to be healthy have no past injuries to the recording site, and some studies ask participants to refrain from consuming alcoholic and caffeinated beverages for 12 hours before the measurements (Natov et al., 2016). This research required a fair and true representation of the workforce, and variables affecting results were noted as required, such as injuries, health issues, and medications. This point was crucial for future research on forestry operators; if an individual can operate a machine, they should be considered for inclusion in trials assessing machine operators.

No conclusive statements can be presented regarding how operator experience levels affected the results in the research trial. It could be hypothesised that the more experienced operators can maintain higher engagement levels with the biofeedback display due to a higher level of automatic behaviours that have been established (Rasmussen, 1983; Gellerstedt, 2002). Research is required to assess how novice and expert operators engage with this technology.

In this particular research trial, it is crucial to acknowledge that only a specific muscle region directly beneath the sensor was observed (McManus et al., 2020). As a result, it is not possible to extrapolate the findings of this trial to encompass muscle activity of surrounding muscles or the body. This limitation is one of several drawbacks associated with employing surface EMG systems. Another limitation pertains to the analysis itself, as operators were solely compared against themselves. The scope of this research aim did not encompass making comparisons across operators. It is important to note that only essential signal processing and time normalisation techniques were employed for comparing control and biofeedback trials. Additionally, amplitude normalisation was not performed since all recordings were obtained within one session. These constraints prevent drawing further conclusions due to the multitude of variables involved and the concise nature of the research scope. It is also necessary to acknowledge that variability exists in electrode placement between operators during this research trial. In their comprehensive review, Al-Mulla et al. (2011) recognised the challenge of electrode placement variability, as Finni and Cheng (2009) discussed. Despite the best efforts of trained professionals, the electrode placement variability did not differ. According to Al-Mulla et al. (2011), the optimal objective for electrode placement is to ensure placement along the muscle midpoint.

6.3 Future research

This section explores possible research directions involving EMG and biofeedback training. This section outlines proposed enhancements to the present research trial and potential applications and alternative system recommendations to be considered in future studies.

The current trial design should be extended to include a post-biofeedback recording to capture any residual effect from biofeedback training. Other research trials have captured improvements over time and the life of those improvements (Morales-Sánchez et al., 2022). Future data processing will include amplitude analysis to allow comparisons of operators, machines, tasks, and sides of the body. Furthermore, a potential avenue for research could involve creating a system that offers ongoing and immediate biofeedback during the initial stages of work. As the process progresses, the biofeedback could gradually decrease to adjust the intensity based on the operator's requirements. Another future improvement to this research trial's experimental design would be using a system that displays biofeedback on a tablet and is controlled by a laptop outside the cab would benefit future research. This system would give researchers more control during training and eliminate the need to enter the cab to start and stop recordings. However, concerns arise regarding the security of the signal connection. Any signal extender or screen mirroring system must be tested for its range extension capabilities and potential issues in a forest environment. Forest canopies can scatter and reflect signals, impacting technologies like AM/FM radio, satellite communication, GPS, lidar, and radar (Holden et al., 2001; Wright et al., 2017).

Biofeedback training can also be utilised to examine the physical and physiological stressors experienced by machine operators when working on slopes. As machines on slopes conduct more harvesting, capturing the physiological measurements of operators in challenging environments is crucial. The BTS FREEEMG system (BTS Bioengineering) has excellent potential for future research on operators in steep slope harvesting.

Another future research avenue to explore would be the employment of a multimodal system of physiological (EMG, ECG, EEG) sensors and biomechanical sensors such as integrated inertial measurement units (IMU), accelerometers, gyroscopes, and magnetometers sensors could provide a detailed picture of the forces and stressors on the operator while working. This system would add to the literature and allow for further conception and deployment of targeted intervention tools for WRMSDs. In this

context, emerging wearable devices can provide a biofeedback signal to maximise effects and possible improvements.

6.4 Strengths and limitations

This section discusses the strengths and limitations associated with employing EMG systems. The strengths lie in the latest technological advancements, resulting in the availability of cost-effective sensors that maintain high-performance levels and capabilities for research purposes. Limitations are presented concerning overall usability and specific constraints of EMG are addressed, along with alternative strategies to consider.

Technology advancement means that wearable technology is now robust, lightweight, portable, wireless, powerful, secure and can produce quality signals. The pilot trial revealed the significance of selecting high-performance equipment suitable for research purposes. Contrary to common belief, these highly sophisticated systems need not be expensive. Commercial research level EMG devices can be expensive, but more recently, low-cost EMG devices are becoming more readily available and are just as capable (Škvor et al., 2022). For example, Fortune et al. (2019) detail an open-source low-cost design (USD \$112 for one, USD \$750 for ten) which is easily adaptable to the researcher/designer's needs. This device can capture high quality signals with low baseline noise and line noise rejection, resulting in a sensitive device that provides great opportunities for researchers to incorporate EMG systems. Barański and Grzeczka (2017) also present a low budget EMG signal preamplifier circuit design. Additionally, signal processing software such as MATLAB (requires a licence), Octave (free), and many more are available online. Wearable sensors like the BTS FREEEMG allow researchers to extend the scope of their research to previously untouchable hypotheses.

A limitation of the general use of these technologies is how crucial it is to have an understanding of the precise techniques used to capture, analyse, and interpret the basic biophysics when using surface EMG devices. Although there are resources available that offer guidance on EMG signal processing, the information is often presented in a way that assumes readers have an engineering or technical

background. Additionally, these resources may assume the reader possesses coding experience and the necessary resources to create customized code for signal analysis. It is still crucial for users to have a basic understanding of signal processing to select appropriate analysis parameters for different conditions and be able to justify their choices when interpreting and reporting results (McManus et al., 2020; Merletti et al., 2016).

Surface EMG has limitations when assessing more complex functions in muscles. EMG while not directly indicating the muscular force generated can help gauge the extent of electrical activity compared to an individual's maximum capacity. Advanced systems have gained popularity as they can address more intricate questions related to muscle functionality. Shear wave elastography (SWE) has become popular due to its non-invasive and quantitative approach to measuring muscle stiffness and other features, allowing for the estimation of changes in muscle force. SWE is also being utilised to quantify alterations in muscle stiffness associated with the progression and treatment of musculoskeletal and neurological conditions (Hug et al., 2015; Lee et al., 2016; Xie et al., 2023). Furthermore, ultrasound elastography provides valuable insights into the relationship between muscle structure and function by measuring individual muscle mechanical properties ((Brandenburg et al., 2014). Electrode arrays or grids have grown in popularity, offering several advantages over traditional EMG recordings. High-density EMG arrays allow the sampling of the EMG signal from multiple locations above the muscle, allowing for analysis of its spatial distribution (Cescon et al., 2008). However, a significant drawback of EMG array recordings is the complexity involved in their analysis and interpretation (McManus et al., 2020).

6.5 Reflection

These concluding remarks encapsulate my final reflections on the research.

The primary objective of this research was to assess the effectiveness of EMG biofeedback training. This technology could be used to manage musculoskeletal disorders in the forestry industry. The long-term goal being to implement an effective tool to minimise muscle tension and fatigue to reduce injuries and pain associated with

operating machines (Axelsson & Pontén, 1990). Following extensive exploration of the current literature, this long-term goal could be seen as overly ambitious. The relationship between muscle tension, fatigue, and pain is complex and not yet fully understood. Muscle tension is a complex phenomenon that comprises both subjective and objective components (Pluess et al., 2009; Westgaard, 1999). Understanding how muscles function is complicated by various factors, such as muscle fibre type, length, and velocity, which affect the relationship between electrical and mechanical muscle activity (Roberts & Gabaldón, 2008). Surface EMG can record muscle activity, but this activity is only indicative of muscle tension (Annoni Elizabeth et al., 2020; Pluess et al., 2009). Additionally, evidence suggests that EMG muscle activity does not have a clear correlation with pain responses (Bansevicius et al., 1997; Leistad et al., 2006; Westgaard, 1999). This lack of correlation and uncertainty around muscle tension (Dieterich et al., 2020) indicates the need for more research. Despite the limited understanding of how muscle activity, tension, and pain are related, EMG biofeedback training has been yielding positive results and gaining popularity ((Ankur et al., 2020; Bowman et al., 2021; Morales-Sánchez et al., 2022).

Chapter 7 Conclusion

The research presented here focused on the effectiveness and applicability of EMG biofeedback training on machine operators. The study utilised the BTS FREEEMG 1000 (BTS Bioengineering) system to capture and present the operator's EMG signal and measure the change in muscle activity during training. The experimental design aimed to capture any potential differences that could be achieved through this training tool. The findings suggest a noticeable difference in average muscle activity between the control and biofeedback training trials. Overall, the results indicated a decrease in muscle activity among most operators during the biofeedback training. Specifically, out of the 13 *t*-tests conducted on the left trapezius muscle, 10 displayed a decrease in muscle activity. Similarly, 11 out of the 13 *t*-tests indicated a reduction in muscle activity in the right trapezius muscle. These findings suggest that biofeedback holds significant potential for reducing muscle activity in forestry operators and supports the alternative hypothesis H_a : EMG biofeedback training affects muscle activity (Chapter 1.5). Further examination is required, and additional trials should be conducted.

References

- Akay, A., Orhan, E., & John, S. (2004). Determining Productivity of Mechanized Harvesting Machines. *Journal of Applied Sciences*, 4, 100-105. <https://doi.org/10.3923/jas.2004.100.105>
- Al-Mulla, M. R., Sepulveda, F., & Colley, M. (2011). A review of non-invasive techniques to detect and predict localised muscle fatigue. *Sensors (Basel)*, 11(4), 3545-3594. <https://doi.org/10.3390/s110403545>
- Ankur, B., Viney, D., Jorge, A., Nikola, U., Kestutis, S., Nuno, L., Kurtis, A., & Reeche, B. (2020). The impact of electromyographic (EMG) biofeedback training on reducing shoulder pain in WB players. *International Conference of Sports Science- AESA*, (3), 24. <https://journal.aesasport.com/index.php/AESA-Conf/article/view/170>
- Annoni Elizabeth, M., Gu, J., Thakur Pramodsingh, H., Clark Bryan, A., & Srivastava Kyle, H. (2020). *Pain management based on muscle tension measurements* (US Patent No. US 10729905 B2). <https://lens.org/016-830-092-793-523>
- Artoni, F., Barsotti, A., Guanziroli, E., Micera, S., Landi, A., & Molteni, F. (2018). Effective Synchronization of EEG and EMG for Mobile Brain/Body Imaging in Clinical Settings. *Frontiers in Human Neuroscience*, 11. <https://doi.org/10.3389/fnhum.2017.00652>
- Attebrant, M., Winkel, J., Mathiassen, S. E., & Kjellberg, A. (1997). Shoulder-arm muscle load and performance during control operation in forestry machines: Effects of changing to a new arm rest, lever and boom control system. *Applied Ergonomics*, 28(2), 85-97. [https://doi.org/10.1016/S0003-6870\(96\)00050-6](https://doi.org/10.1016/S0003-6870(96)00050-6)
- Axelsson, S. Å., & Pontén, B. (1990). New ergonomic problems in mechanized logging operations. *International Journal of Industrial Ergonomics*, 5(3), 267-273. [https://doi.org/10.1016/0169-8141\(90\)90062-7](https://doi.org/10.1016/0169-8141(90)90062-7)
- Bansevicus, D., Westgaard, R. H., & Jensen, C. (1997). Mental Stress of Long Duration: EMG Activity, Perceived Tension, Fatigue, and Pain Development in Pain-Free Subjects. *Headache: The Journal of Head and Face Pain*, 37(8), 499-510. <https://doi.org/10.1046/j.1526-4610.1997.3708499.x>
- Barański, R., & Grzeczka, A. (2017). Simple and low cost electromyography signal amplifier. *Diagnostyka*, 18(4), 69-77. <https://www.infona.pl/resource/bwmeta1.element.baztech-bb08e37a-8ac9-4e02-a239-edc461f7ebad>
- Basmajian, J. V., & Luca, C. J. d. (1985). Muscles alive. *Their functions revealed by electromyography*. <https://cir.nii.ac.jp/crid/1570854174693160448>
- Bifulco, P., Cesarelli, M., Fratini, A., Ruffo, M., Pasquariello, G., & Gargiulo, G. (2011, May). A wearable device for recording of biopotentials and body movements. *IEEE International Symposium on Medical Measurements and Applications*, 2011, 469-472. <https://doi.org/10.1109/MeMeA.2011.5966735>
- Bowman, T., Gervasoni, E., Arienti, C., Lazzarini, S. G., Negrini, S., Crea, S., Cattaneo, D., & Carrozza, M. C. (2021). Wearable Devices for Biofeedback Rehabilitation: A Systematic Review and Meta-Analysis to Design Application Rules and Estimate the Effectiveness on Balance and Gait Outcomes in Neurological Diseases. *Sensors (Basel)*, 21(10). <https://doi.org/10.3390/s21103444>

- Brandenburg, J. E., Eby, S. F., Song, P., Zhao, H., Brault, J. S., Chen, S., & An, K.-N. (2014). Ultrasound Elastography: The New Frontier in Direct Measurement of Muscle Stiffness. *Archives of Physical Medicine and Rehabilitation*, 95(11), 2207-2219. <https://doi.org/10.1016/j.apmr.2014.07.007>
- BTS Bioengineering. (n.d.). *FREEEMG, Wireless Surface EMG*. BTS Bioengineering. <https://www.btsbioengineering.com/products/freeemg/>
- Buckle, P. (2005). Ergonomics and musculoskeletal disorders: overview. *Occupational Medicine*, 55(3), 164-167. <https://doi.org/10.1093/occmed/kqi081>
- Cescon, C., Rebecchi, P., & Merletti, R. (2008). Effect of electrode array position and subcutaneous tissue thickness on conduction velocity estimation in upper trapezius muscle. *Journal of Electromyography and Kinesiology*, 18(4), 628-636. <https://doi.org/10.1016/j.jelekin.2007.01.005>
- Chowdhury, R. H., Reaz, M. B., Ali, M. A., Bakar, A. A., Chellappan, K., & Chang, T. G. (2013). Surface electromyography signal processing and classification techniques. *Sensors (Basel)*, 13(9), 12431-12466. <https://doi.org/10.3390/s130912431>
- Competenz. (2015). *Best Practice Guidelines for Mechanised Harvesting and Processing*. <https://safetree.nz/wp-content/uploads/2015/02/Mechanised-Harvesting-and-Processing.pdf>
- Criado, L., de La Fuente, A., Heredia, M., Montero, J., Albaladejo, A., & Criado, J. M. (2016). Electromyographic biofeedback training for reducing muscle pain and tension on masseter and temporal muscles: A pilot study. *Journal of Clinical and Experimental Dentistry*, 8(5), 571-576. <https://doi.org/10.4317/jced.52867>
- Deschodt-Arsac, V., Lalanne, R., Spiluttini, B., Bertin, C., & Arsac, L. M. (2018). Effects of heart rate variability biofeedback training in athletes exposed to stress of university examinations. *PLoS ONE (Public Library of Science)*, 13(7). <https://doi.org/10.1371/journal.pone.0201388>
- Dhein, W., Wagner Neto, E. S., Miranda, I. F., Pinto, A. B., Moraes, L. R., & Loss, J. F. (2020). Effects of Kinesio Taping on scapular kinematics and electromyographic activity in subjects with shoulder impingement syndrome. *Journal of Bodywork and Movement Therapies*, 24(2), 109-117. <https://doi.org/10.1016/j.jbmt.2019.10.007>
- Di Leo, G., & Sardanelli, F. (2020). Statistical significance: p value, 0.05 threshold, and applications to radiomics—reasons for a conservative approach. *European Radiology Experimental*, 4(1), 18. <https://doi.org/10.1186/s41747-020-0145-y>
- Dieterich, A. V., Haueise, A., & Gizzi, L. (2022). Feeling stiff...but what does it mean objectively? : Can you measure muscle tension?. *Schmerz (Berlin, Germany)*, 36(4), 242-247. <https://doi.org/10.1007/s00482-022-00636-y>
- Ding, J., Wexler, A. S., & Binder-Macleod, S. A. (2000). A predictive model of fatigue in human skeletal muscles. *Journal of Applied Physiology*, 89(4), 1322-1332. <https://doi.org/10.1152/jappl.2000.89.4.1322>
- Dvořák, J., Natov, P., Natovová, L., Krilek, J., & Kováč, J. (2016). Operator's physical workload in simulated logging and timber bucking by harvester. *Journal of Forest Science*, 62(5), 236-244. <https://doi.org/10.17221/21/2016-JFS>
- Farina, D., Madeleine, P., Graven-Nielsen, T., Merletti, R., & Arendt-Nielsen, L. (2002). Standardising surface electromyogram recordings for assessment of activity and fatigue in the human upper trapezius muscle. *European Journal of Applied Physiology*, 86(6), 469-478. <https://doi.org/10.1007/s00421-001-0574-0>

- Finni, T., & Cheng, S. (2009). Variability in lateral positioning of surface EMG electrodes. *Journal of Applied Biomechanics*, 25(4), 396-400. <https://doi.org/10.1123/jab.25.4.396>
- Fortune, B. C., Pretty, C. G., Chatfield, L. T., McKenzie, L. R., & Hayes, M. P. (2019). Low-cost active electromyography. *HardwareX*, 6. <https://doi.org/10.1016/j.ohx.2019.e00085>
- Gallis, C. (2006). Work-related prevalence of musculoskeletal symptoms among Greek forest workers. *International Journal of Industrial Ergonomics*, 36(8), 731-736. <https://doi.org/10.1016/j.ergon.2006.05.007>
- Gallis, C. (2013). Increasing productivity and controlling of work fatigue in forest operations by using prescribed active pauses: A selective review. *Croatian Journal of Forest Engineering*, 34(1), 103-112. <https://www.scopus.com/inward/record.uri?eid=2-s2.0-84880799755&partnerID=40&md5=dd0d6ab0e9a59b085ccdeae55dabb44f>
- Gellerstedt, S. (1993). *Work and health in forest work - a multivariate study of cutters and machine operators*. [Doctoral Thesis]. Department of Operational Efficiency, College of Forestry, Garpenberg, Sweden. Doktorsavhandlingar. <https://www.scopus.com/inward/record.uri?eid=2-s2.0-0027807627&partnerID=40&md5=58c680b9cfc115d9e37dedfe05a36a92>
- Gellerstedt, S. (1997). Mechanised cleaning of young forest - The strain on the operator. *International Journal of Industrial Ergonomics*, 20(2), 137-143. [https://doi.org/10.1016/S0169-8141\(96\)00046-7](https://doi.org/10.1016/S0169-8141(96)00046-7)
- Gellerstedt, S. (2002). Operation of the Single-Grip Harvester: Motor-Sensory and Cognitive Work. *International Journal of Forest Engineering*, 13(2), 35-47. <https://doi.org/10.1080/14942119.2002.10702461>
- Ghaffariyan, M. R. (2016). Analysis of forestry work accidents in five Australian forest companies for the period 2004 to 2014. *Journal of Forest Science*, 62(12), 545-552. <https://doi.org/10.17221/80/2016-JFS>
- Gokgoz, E., & Subasi, A. (2015). Comparison of decision tree algorithms for EMG signal classification using DWT. *Biomedical Signal Processing and Control*, 18, 138-144. <https://doi.org/10.1016/j.bspc.2014.12.005>
- Grzywiński, W., Wandycz, A., Tomczak, A., & Jelonek, T. (2016). The prevalence of self-reported musculoskeletal symptoms among loggers in Poland. *International Journal of Industrial Ergonomics*, 52, 12-17. <https://doi.org/10.1016/j.ergon.2015.07.003>
- Habibi, E., & Soury, S. (2015). The effect of three ergonomics interventions on body posture and musculoskeletal disorders among staff of Isfahan Province Gas Company. *Journal of Education and Health Promotion*, 4, 65. <https://doi.org/10.4103/2277-9531.162386>
- Häggröm, C. (2015). *Human Factors in Mechanized Cut-to-Length Forest*. [Doctoral Thesis]. Department of Forest Biomaterials and Technology, Swedish University of Agricultural Sciences. <https://res.slu.se/id/publ/67031>
- Hansson, G.-Å., Balogh, I., Ohlsson, K., Pålsson, B., Rylander, L., & Skerfving, S. (2000). Impact of physical exposure on neck and upper limb disorders in female workers. *Applied Ergonomics*, 31(3), 301-310. [https://doi.org/10.1016/S0003-6870\(99\)00047-2](https://doi.org/10.1016/S0003-6870(99)00047-2)
- Hansson, J. E. (1990). Ergonomic design of large forestry machines. *International Journal of Industrial Ergonomics*, 5(3), 255-266. [https://doi.org/10.1016/0169-8141\(90\)90061-6](https://doi.org/10.1016/0169-8141(90)90061-6)

- Harstela, P. (1990). Work postures and strain of workers in nordic forest work: A selective review. *International Journal of Industrial Ergonomics*, 5(3), 219-226. [https://doi.org/10.1016/0169-8141\(90\)90058-A](https://doi.org/10.1016/0169-8141(90)90058-A)
- Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research. *Advances in Psychology*, 52, 139-183. [https://doi.org/10.1016/S0166-4115\(08\)62386-9](https://doi.org/10.1016/S0166-4115(08)62386-9)
- Holden, N. M., Martin, A. A., Owende, P. M. O., & Ward, S. M. (2001). A Method For Relating GPS Performance To Forest Canopy. *International Journal of Forest Engineering*, 12(2), 51-56. <https://doi.org/10.1080/14942119.2001.10702446>
- Hug, F., Tucker, K., Gennisson, J. L., Tanter, M., & Nordez, A. (2015). Elastography for Muscle Biomechanics: Toward the Estimation of Individual Muscle Force. *Exercise and sport sciences reviews*, 43(3), 125-133. <https://doi.org/10.1249/jes.0000000000000049>
- Jang, M. H., Ahn, S. J., Lee, J. W., Rhee, M. H., Chae, D., Kim, J., & Shin, M. J. (2018). Validity and Reliability of the Newly Developed Surface Electromyography Device for Measuring Muscle Activity during Voluntary Isometric Contraction. *Computational and Mathematical Methods in Medicine*, 2018, 9. <https://doi.org/10.1155/2018/4068493>
- Jankovský, M., Merganič, J., Allman, M., Ferencík, M., & Messingerová, V. (2018). The cumulative effects of work-related factors increase the heart rate of cabin field machine operators. *International Journal of Industrial Ergonomics*, 65, 173-178. <https://doi.org/10.1016/j.ergon.2017.08.003>
- Kale, S. N., & Dudul, S. V. (2009). Intelligent Noise Removal from EMG Signal Using Focused Time-Lagged Recurrent Neural Network. *Applied Computational Intelligence and Soft Computing*, 2009, 1-12. <https://doi.org/10.1155/2009/129761>
- Kamonseki, D. H., Calixtre, L. B., Barreto, R. P. G., & Camargo, P. R. (2021). Effects of electromyographic biofeedback interventions for shoulder pain and function: Systematic review and meta-analysis. *Clinical Rehabilitation*, 35(7), 952-963. <https://doi.org/10.1177/0269215521990950>
- Kirk, P., Byers, J., Parker, R., & Sullman, M. (1997). Mechanisation developments within the New Zealand forest industry: the human factors. *Journal of Forest Engineering*, 8(1), 75-80. <https://doi.org/10.1080/08435243.1997.10702698>
- Klun, J., & Medved, M. (2007). Fatal accidents in forestry in some European countries. *Croatian Journal of Forest Engineering*, 28(1), 55-62. <https://www.scopus.com/inward/record.uri?eid=2-s2.0-34247232609&partnerID=40&md5=f0309323678eabf92b6d553e50593205>
- Kuruganti, U., Murphy, T. P., & Dickinson, G. T. (2011). A preliminary investigation of upper limb muscle activity during simulated Canadian forest harvesting operations. *Work (A Journal of Prevention, Assessment & Rehabilitation)*, 39(4), 491-498. <https://doi.org/10.3233/WOR-2011-1199>
- Lee, S. S., Gaebler-Spira, D., Zhang, L. Q., Rymer, W. Z., & Steele, K. M. (2016). Use of shear wave ultrasound elastography to quantify muscle properties in cerebral palsy. *Clinical biomechanics (Bristol, Avon)*, 31, 20-28. <https://doi.org/10.1016/j.clinbiomech.2015.10.006>
- Leistad, R., Sand, T., Westgaard, R., Nilsen, K., & Stovner, L. (2006). Stress-Induced Pain and Muscle Activity in Patients with Migraine and Tension-Type Headache. *Cephalalgia (Journal of the International Headache Society)*, 26(1), 64-73. <https://doi.org/10.1111/j.1468-2982.2005.00997.x>

- Lilley, R., Feyer, A.-M., Kirk, P., & Gander, P. (2002). A survey of forest workers in New Zealand: Do hours of work, rest, and recovery play a role in accidents and injury? *Journal of safety research*, 33(1), 53-71.
[https://doi.org/10.1016/S0022-4375\(02\)00003-8](https://doi.org/10.1016/S0022-4375(02)00003-8)
- MacDonald, A. J. (1999). *Harvesting systems and equipment in British Columbia*. British Columbia, Ministry of Forests, Forest Practices Branch.
<http://dspace.ualca.cl/handle/1950/2072>
- Macků, J., & Dvořák, J. (2013). A comparative analysis of neck muscle tension in a harvester operator compared with chainsaw and horse skidding operator and with normal human activities. *Journal of Forest Science*, 59(8), 301-305.
<https://doi.org/10.17221/5/2013-jfs>
- McKain, D. (2019). *Adolescent Chronic Stress: Brain Function and Treatment for Depression and Anxiety*. In *Chronic Stress and Its Effect on Brain Structure and Connectivity*. IGI Global. <https://doi.org/10.4018/978-1-5225-7513-9.ch002>
- McLean, L., & Rickards, J. (1998). Ergonomics Codes of Practice: The Challenge of Implementation in Canadian Workplaces. *Journal of Forest Engineering*, 9(1), 55-64. <https://doi.org/10.1080/08435243.1998.10702712>
- McManus, L., De Vito, G., & Lowery, M. M. (2020). Analysis and biophysics of surface EMG for physiotherapists and kinesiologists: Toward a common language with rehabilitation engineers. *Frontiers in neurology*, 11.
<https://doi.org/10.3389/fneur.2020.576729>
- Melemez, K. (2015). Risk factor analysis of fatal forest harvesting accidents: A case study in Turkey. *Safety Science*, 79, 369-378.
<https://doi.org/10.1016/j.ssci.2015.07.004>
- Merletti, R., Vieira, T. M., & Farina, D. (2016). *Techniques for information extraction from the surface EMG signal high-density surface EMG*. In *Surface Electromyography: Physiology, Engineering and Applications*.
<https://doi.org/10.1002/9781119082934.ch05>
- Miranda, H., Viikari-Juntura, E., Martikainen, R., Takala, E.-P., & Riihimäki, H. (2001). Physical exercise and musculoskeletal pain among forest industry workers. *Scandinavian Journal of Medicine & Science in Sports*, 11(4), 239-246.
<https://doi.org/10.1034/j.1600-0838.2001.110408.x>
- Morales-Sánchez, V., Falcó, C., Hernández-Mendo, A., & Reigal, R. E. (2022). Efficacy of Electromyographic Biofeedback in Muscle Recovery after Meniscectomy in Soccer Players. *Sensors (Basel)*, 22(11).
<https://doi.org/10.3390/s22114024>
- MPI, M. f. P. I. (2023, June 19). *Forestry and wood processing data*. Ministry for Primary Industries. <https://www.mpi.govt.nz/forestry/forest-industry-and-workforce/forestry-wood-processing-data/>
- Muggleton, J. M., Allen, R., & Chappell, P. H. (1999). Hand and arm injuries associated with repetitive manual work in industry: a review of disorders, risk factors and preventive measures. *Ergonomics*, 42(5), 714-739.
<https://doi.org/10.1080/001401399185405>
- Murphy, T., & Oliver, M. L. (2011). Evaluation of a dynamic armrest for hydraulic-actuation controller use. *Applied Ergonomics*, 42(5), 692-698.
<https://doi.org/10.1016/j.apergo.2010.11.002>
- Natov, P., Dvořák, J., & Natovova, L. (2016). Psychophysiological Workload During Log Bucking By Timber Harvester. *Efficiency and Responsibility in Education 2016 conference, Czech University of Life Sciences, Prague* .

https://www.researchgate.net/publication/304581120_Psychophysiological_Workload_During_Log_Bucking_By_Timber_Harvester

- Nussbaum, M. A., Clark, L. L., Lanza, M. A., & Rice, K. M. (2001). Fatigue and Endurance Limits During Intermittent Overhead Work. *AIHAJ - American Industrial Hygiene Association*, 62(4), 446-456.
<https://doi.org/10.1080/15298660108984646>
- Østensvik, T., Belbo, H., & Veiersted, K. B. (2019). An automatic pre-processing method to detect and reject signal artifacts from full-shift field-work sEMG recordings of bilateral trapezius activity. *Journal of Electromyography and Kinesiology*, 46, 49-54. <https://doi.org/10.1016/j.jelekin.2019.03.009>
- Paini, A. C., Lopes, E. D. S., de Souza, A. P., de Oliveira, F. M., & Rodrigues, C. K. (2019). Repetitive motion and postural analysis of machine operators in mechanized wood harvesting operations. *Cerne*, 25(2), 214-220.
<https://doi.org/10.1590/01047760201925022617>
- Parker, R., Wright, L. (1999). *EMG - Biofeedback for Forest Harvesting machine operators*. [unpublished paper presentation] NZ Ergonomics Society Conference.
- Peake, J. M., Kerr, G., & Sullivan, J. P. (2018). A Critical Review of Consumer Wearables, Mobile Applications, and Equipment for Providing Biofeedback, Monitoring Stress, and Sleep in Physically Active Populations. *Frontiers in Physiology*, 9, 743. <https://doi.org/10.3389/fphys.2018.00743>
- Pluess, M., Conrad, A., & Wilhelm, F. H. (2009). Muscle tension in generalized anxiety disorder: a critical review of the literature. *Journal of Anxiety Disorders*, 23(1), 1-11. <https://doi.org/10.1016/j.janxdis.2008.03.016>
- Preston, D. C., & Shapiro, B. E. (2020). *Electromyography and Neuromuscular Disorders*. In *Clinical-Electrophysiologic-Ultrasound Correlations*. Elsevier Health Sciences. <https://books.google.co.nz/books?id=aRPYDwAAQBAJ>
- Raez, M. B., Hussain, M. S., & Mohd-Yasin, F. (2006). Techniques of EMG signal analysis: detection, processing, classification and applications. *Biological Procedures Online*, 8, 11-35. <https://doi.org/10.1251/bpo115>
- Rasmussen, J. (1983). Skills, rules, and knowledge; signals, signs, and symbols, and other distinctions in human performance models. *IEEE Transactions on Systems, Man, and Cybernetics*, 13(3), 257-266.
<https://doi.org/10.1109/TSMC.1983.6313160>
- Raymond, K. (2010). Innovative Harvesting Solutions: A Step Change Harvesting Research. Programme. *New Zealand Journal of Forestry*, 55(3), 4-9.
http://www.nzjf.org.nz/free_issues/NZJF55_3_2010/739EA605-0BCC-4828-82A0-6C3BDF6CF91B.pdf
- Rehn, B., Nilsson, T., Lundström, R., Hagberg, M., & Burström, L. (2009). Neck pain combined with arm pain among professional drivers of forest machines and the association with whole-body vibration exposure. *Ergonomics*, 52(10), 1240-1247. <https://doi.org/10.1080/00140130902939889>
- Resility. (n.d.). *Resility Wireless EMG Biofeedback Sensor*. Resility Health.
<https://resilityhealth.com/>
https://web.archive.org/web/202200000000000*/https://resilityhealth.com/
- Roberts, T. J., & Gabaldón, A. M. (2008). Interpreting muscle function from EMG: lessons learned from direct measurements of muscle force. *Journal of the Society for Integrative and Comparative Biology*, 48(2), 312-320.
<https://doi.org/10.1093/icb/icn056>

- Santos, J., Baptista, J. S., Monteiro, P. R. R., Miguel, A. S., Santos, R., & Vaz, M. A. P. (2016). The influence of task design on upper limb muscles fatigue during low-load repetitive work: A systematic review. *International Journal of Industrial Ergonomics*, 52, 78-91. <https://doi.org/10.1016/j.ergon.2015.09.010>
- Sarillee, M., Hariharan, M., Anas, M. N., Omar, M. I., Aishah, M. N., & Oung, Q. W. (2014). Non-invasive techniques to assess muscle fatigue using biosensors: A review. In *2014 IEEE 5th Control and System Graduate Research Colloquium* (pp. 187-192). IEEE. <https://doi.org/10.1109/ICSGRC.2014.6908719>
- Shannon, C. E. (1949). Communication in the Presence of Noise. *Proceedings of the IRE*, 37(1), 10-21. <https://doi.org/10.1109/JRPROC.1949.232969>
- Silva, E. P., Minette, L. J., Sanches, A. L. P., de Souza, A. P., Silva, F. L., & Mafra, S. C. T. (2014). Prevalence of musculoskeletal symptoms in forest harvesting machine operators. *Revista Arvore*, 38(4), 739-745. <https://doi.org/10.1590/S0100-67622014000400017>
- Škvor, P., Jankovský, M., Natov, P., & Dvořák, J. (2023). Evaluation of stress loading for logging truck drivers by monitoring changes in muscle tension during a work shift. *Silva Fennica*, 57. <https://doi.org/10.14214/sf.10709>
- Škvor, P., Jankovský, M., Natov, P., Dvořák, J., & Zlatuška, K. (2022). The Effect of Different Road Types on Timber Truck Drivers by Assessing the Load Environment of Drivers by Monitoring Changes in Muscle Tension. *Forests (Journal of forestry and forest ecology)*, 13(10), 1565. <https://www.mdpi.com/1999-4907/13/10/1565>
- Sokoler, T., & Bagalkot, N. L. (2017). Watching Your Back While Riding Your Bike. *Human-Computer Interaction - INTERACT 2017*. https://doi.org/10.1007/978-3-319-67684-5_19
- StatsNZ. (2022). *Injury statistics – work-related claims: 2021*. Stats NZ. <https://www.stats.govt.nz/information-releases/injury-statistics-work-related-claims-2021/>
- Thabrew, H., Ruppeltdt, P., & Sollers, J. J. (2018). Systematic Review of Biofeedback Interventions for Addressing Anxiety and Depression in Children and Adolescents with Long-Term Physical Conditions. *Applied Psychophysiology and Biofeedback*, 43(3), 179-192. <https://doi.org/10.1007/s10484-018-9399-z>
- Tsioras, P. A., Rottensteiner, C., & Stampfer, K. (2014). Wood harvesting accidents in the Austrian State Forest Enterprise 2000–2009. *Safety Science*, 62, 400-408. <https://doi.org/10.1016/j.ssci.2013.09.016>
- Veiersted, K. B., Forsman, M., Hansson, G.-Å., & Mathiassen, S. E. (2013). Assessment of time patterns of activity and rest in full-shift recordings of trapezius muscle activity – Effects of the data processing procedure. *Journal of Electromyography and Kinesiology*, 23(3), 540-547. <https://doi.org/10.1016/j.jelekin.2012.12.004>
- Visser, R. S., K. (2015). Expanding Ground-based Harvesting onto Steep Terrain: A Review. *Croatian Journal of Forest Engineering, Journal for Theory and Application of Forestry Engineering*, 36(2), 321-331. https://www.researchgate.net/publication/283677315_Expanding_Ground-based_Harvesting_onto_Steep_TerrainA_Review
- Wasserstein, R. L., & Lazar, N. A. (2016). The ASA Statement on p-Values: Context, Process, and Purpose. *The American Statistician*, 70(2), 129-133. <https://doi.org/10.1080/00031305.2016.1154108>

- Wasserstein, R. L., Schirm, A. L., & Lazar, N. A. (2019). Moving to a World Beyond “ $p < 0.05$ ”. *The American Statistician*, 73(1), 1-19.
<https://doi.org/10.1080/00031305.2019.1583913>
- Westgaard, R. H. (1999). Muscle Activity as a Releasing Factor for Pain in the Shoulder and Neck. *Cephalalgia (Journal of Headache)*, 19(25), 1-8.
<https://doi.org/10.1177/0333102499019S2501>
- Worksafe. (2022). *Definitions: Musculoskeletal disorders and work-related musculoskeletal disorders*. Worksafe. <https://www.worksafe.govt.nz/topic-and-industry/work-related-health/musculoskeletal-disorders/definitions-musculoskeletal-disorders-and-work-related-musculoskeletal-disorders/>
- Wright, W. C., Wilkinson, B. E., & Cropper, W. P. (2017). Estimating signal loss in pine forests using hemispherical sky oriented photos. *Ecological Informatics*, 38, 82-88. <https://doi.org/10.1016/j.ecoinf.2017.02.002>
- Xie, Y.-J., Wang, S., Gong, Q.-J., Wang, J.-X., Sun, F.-H., Miyamoto, A., Ou, X., Wang, L., Wang, S.-Q., & Zhang, C. (2021). Effects of electromyography biofeedback for patients after knee surgery: A systematic review and meta-analysis. *Journal of Biomechanics*, 120.
<https://doi.org/https://doi.org/10.1016/j.jbiomech.2021.110386>
- Xie, Y., Thomas, L., Johnston, V., & Coombes, B. K. (2023). Cervical and axioscapular muscle stiffness measured with shear wave elastography: A comparison between different levels of work-related neck disability. *Journal of Electromyography and Kinesiology*, 69.
<https://doi.org/10.1016/j.jelekin.2023.102754>

Appendix

Appendix A Terminology

Inspired by Spiers (1985) and Visser (2016)

Mechanisation	The use of machines to carry out selected tree harvesting phases, including felling, delimiting, and processing.
Motor-manual	Work conducted using a chainsaw.
Harvester	A harvester falls into the category of feller directors. It consists of two components: the cutting head and the carrier machine. These machines are designed to perform tasks like tree cutting, removing branches and processing wood.
Processor	A machine with the ability to remove branches and cut stems into logs. This machine's head is equipped with the capability to measure the length and diameter of the tree while it is being processed.
Felling	Severing the tree from the stump.
Landing	The terms "landing," "yarder or hauler sites," "skid sites," and "pads" all refer to locations where logs are extracted to be processed (in whole Tree systems), stored, fleeted, sorted, and loaded onto log trucks.
Forwarders	Forwarders are machines with a driver's compartment and a section for carrying logs. Although forwarders are capable of extracting tree stems, they are better suited for "cut to length" harvesting.
Skidder	A grapple or cable skidder is used to pull the logs. Typically used in whole tree (WT) harvesting systems to collect stems from the tree stand and drag them to a landing.
Fleeting	Positioning stems and logs in preparation for being sorted
Sorting	Sort logs by grade and stack them into piles.
Shovelling	Moving the stems closer to the landing or roadside.
Delimiting	Trimming branches off a stem or log
Production and productivity	Production refers to the number of logs that are handled within a day, either by the operation or for a specific phase. Productivity measures the volume or weight of logs handled during a productive hour excluding any delays. Typically, productivity is associated with phases such as machine felling where it can reach 55 trees per productive hour.

Appendix B Ethics approval document

The University of Waikato
Private Bag 3105
Hamilton, New Zealand, 3240
0800 WAIKATO (924 528)

HECS Human Ethics Committee
Brett Langley
Telephone +64 77 838 4060
Heccs-ethics@waikato.ac.nz



THE UNIVERSITY OF
WAIKATO
Te Whare Wānanga o Waikato

16 December 2021

Brooke O'Connor
Judy Bowen
Richard Parker

Re: HECS Ethics Approval of Application HREC(HECS)2021#48 "Biofeedback on forestry machine operators project"

Dear Brooke:

Thank you for submitting your amended application HREC(HECS)2021#48 for ethical approval.

We are pleased to provide formal approval for your project, including the following activities:

- Recruitment of approximately 10 Forestry machine operators for a study that assess operators' muscle load and stress during harvesting operations
- Fit wearable BTS FREEEMG 1000 electromyography sensors on the participants that will transmit data from target muscle groups in real-time via a wireless link to a recording device while they work on flat terrain in logging operations.
- Provide real-time muscle activity to the participants via a customised biofeedback display, which will allow operators to observe the activity of their monitored muscles and consciously manage the contraction and relaxing of these muscles.
- Conduct a short self-reporting questionnaire with participants to evaluate the effectiveness of biofeedback and useability of the equipment.

Please contact the committee by email (hecs-ethics@waikato.ac.nz) if you wish to make changes to your project as it unfolds, quoting your application number with your future correspondence. Any minor changes or additions to the approved research activities can be handled outside the monthly application cycle.

We wish you all the best with your research.

Kind regards,

A handwritten signature in black ink, appearing to read 'Brett Langley'.

Brett Langley, PhD
Chairperson
HECS Human Ethics Committee
University of Waikato

Appendix C BTS FREEEMG 1000 information
Relevant product information

Installation



9 Installation

9.1 Minimum system requirements for the user workstation

Operating system	Windows 7 Professional - Administrative privileges required
Processor	Intel Core 2 Duo or Intel i3
RAM	4 GB
Video resolution	1280x800
Disk space	200 MB for the application, not including storage for acquired data
USB	2.0

9.2 Recommended system requirements for the user workstation

Operating system	Windows 10 Professional 64 bit - Administrative privileges required
Processor	Intel i5
RAM	8 GB
Video resolution	1920x1080
Disk space	500 GB
USB	2.0 x 3 USB ports
Wifi card/Ethernet Gigabit port	For remote support

9.3 Device and Software installation

Insert the USB flash drive into a USB port of the workstation dedicated to the use of the BTS FREEEMG 1000.



Administrative privileges are required for the installation and use of the device and software. Make sure to log into Windows as a user with administrative rights to install and use the system.

Open the Start menu and select Computer. Double click on the FREEEMG1000 device (Figure 9.1).



Appendix D Participant handouts



BIOFEEDBACK ON FORESTRY MACHINE OPERATORS PROJECT

PARTICIPANT INFORMATION SHEET

You are invited to take part in the Biofeedback on forestry machine operators project. Whether or not you take part is your choice. If you don't want to take part, you don't have to give a reason. This Participant Information Sheet will help you decide if you'd like to take part. It sets out why we are doing the project, what your participation would involve, and what would happen after the project ends.

If you agree to participate in this project, you will be asked to sign the Consent Form on the next page of this document. You will be emailed a copy of both the Participant Information Sheet and the Consent Form to keep. Please make sure you have read and understood all the pages.

Purpose

This project aims to assess operators' muscle load and stress in forestry machines during harvesting operations using electromyography sensors. This work is conducted as part of a Master's project in collaboration with Waikato University. The forest industry in New Zealand has shifted to predominantly mechanised harvesting and processing. Many machine operators sit in a relatively immobile state for hours, causing upper body muscle tension/strain. The project will investigate the machine operators' workstation and their stress and tension levels using EMG sensors. A biofeedback display will provide the machine operator with real-time feedback on their muscle tension. The research is being conducted by Brooke O'Connor of Scion and the University of Waikato.

What is involved?

This study will use electromyography sensors and biofeedback to assess muscle tension/strain in forestry machine operators. Wearable EMG sensors will be installed on the participants to transmit data from target muscle groups in real-time via a wireless link to a recording device. Using the BTS FREEEMG 1000 electromyography sensors, measurements will compare muscle load of machine operators working on flat terrain in logging operations. Also a customised biofeedback display will present a real-time muscle activity display, allowing operators to observe the activity of their monitored muscles and consciously manage the contraction and relaxing of these muscles. A short self-report will be conducted to capture subjective data to evaluate the effectiveness of biofeedback and useability of the equipment.

Confidentiality

Information and data will be collected on digital recording equipment and via note taking and later analysed to interpret findings. Your individual information will remain confidential to the researcher(s), and your name will not be linked to the final documentation. The aggregate information collected will be included in reports, presentations and publications. Electronic recordings will be held at a secure location on a Scion SharePoint and will only be available to project team members with access to the information. Information will be stored for five years following the project completion (31 Dec 2022) and then archived, following prescribed Scion protocols.

Participant Rights

Your participation in this project is entirely voluntary. You have the right to:

- i. Decline to participate or to answer any particular question
- ii. Withdraw from the project at any time during your participation
- iii. Withdraw permission to use the information collected during the three weeks following your participation
- iv. Ask any questions about the project at any time during participation.

Contact

Thank you and if you have any questions about this research or for further information, please contact:
Brooke O'Connor | Researcher | Mobile 027 407 1007 | Email brooke.o'connor@scionresearch.com

This research project has been approved by the Human Research Ethics Committee of the University of Waikato under HREC(HECS)2021#48. For any ethical questions or concerns please contact the Chair of the Committee, email hecs-ethics@waikato.ac.nz, postal address, University of Waikato, Te Whare Wananga o Waikato, Private Bag 3105, Hamilton 3240.

BIOFEEDBACK ON FORESTRY MACHINE OPERATORS PROJECT

CONSENT FORM

I have had the opportunity to read the contents of the Participant Information Sheet for individuals taking part in this Scion and University of Waikato Research Project and to discuss the project with the researcher.

I understand my rights as a participant and that my participation in this research project will be anonymised and that no material that could identify me will be used in any reports on this project.

(Please tick each statement)

- I have been given a full explanation of this project and have had the opportunity to ask questions.
- I understand what is required of me if I agree to take part in the research.
- I understand that participation is voluntary and I may withdraw at any time without penalty.
- Withdrawal of participation will also include the withdrawal of any information I have provided should this remain practically achievable.
- I understand that any information or opinions I provide will be kept confidential to the researcher and that any published or reported results will not identify the participants.
- I understand that all data collected for the project will be kept in locked and secure facilities and/or in password protected electronic form.
- I allow audio and visual recordings to be made, knowing that this footage will be kept securely and could be used for further analyses.
- I understand that I am able to receive a report on the findings of the project by contacting the researcher at the conclusion of the project.
- I understand that I can contact the researcher for further information.
- By signing below, I agree to participate in this research project.

Signature _____ Date _____ / _____ / 2021

Name _____

Machine _____

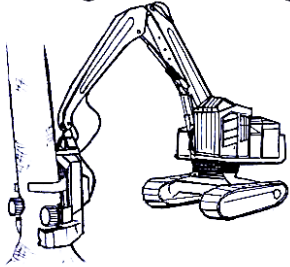
Phone _____

Experience _____ Years

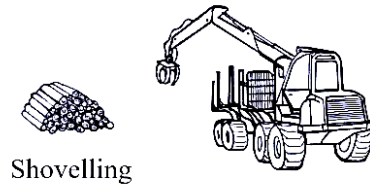
Appendix E Illustration of operational tasks

This illustration presented here offers additional elaboration regarding the tasks outlined in Table 1 Participant Details. This image effectively depicts the specific locations and timings of each task being performed. This allows the reader to visualise each operator in their task, which facilitates a clearer understanding of a typical harvesting operation in New Zealand.

Felling + Processing

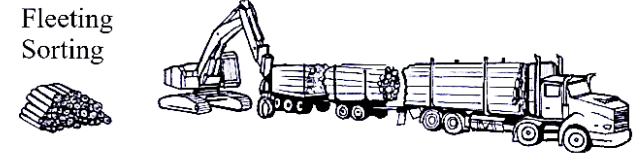


Extraction

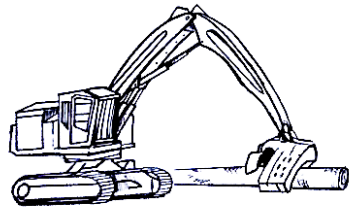


Shovelling

Loading



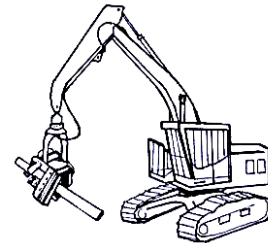
Fleeting
Sorting



Felling



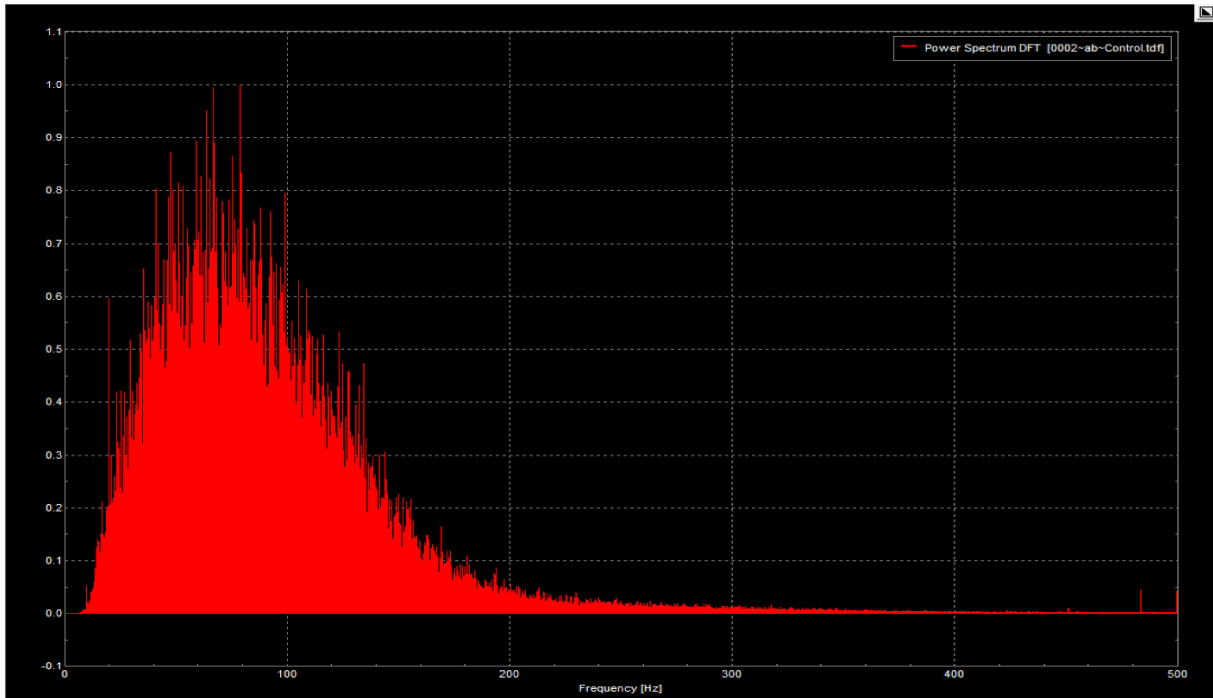
Extraction



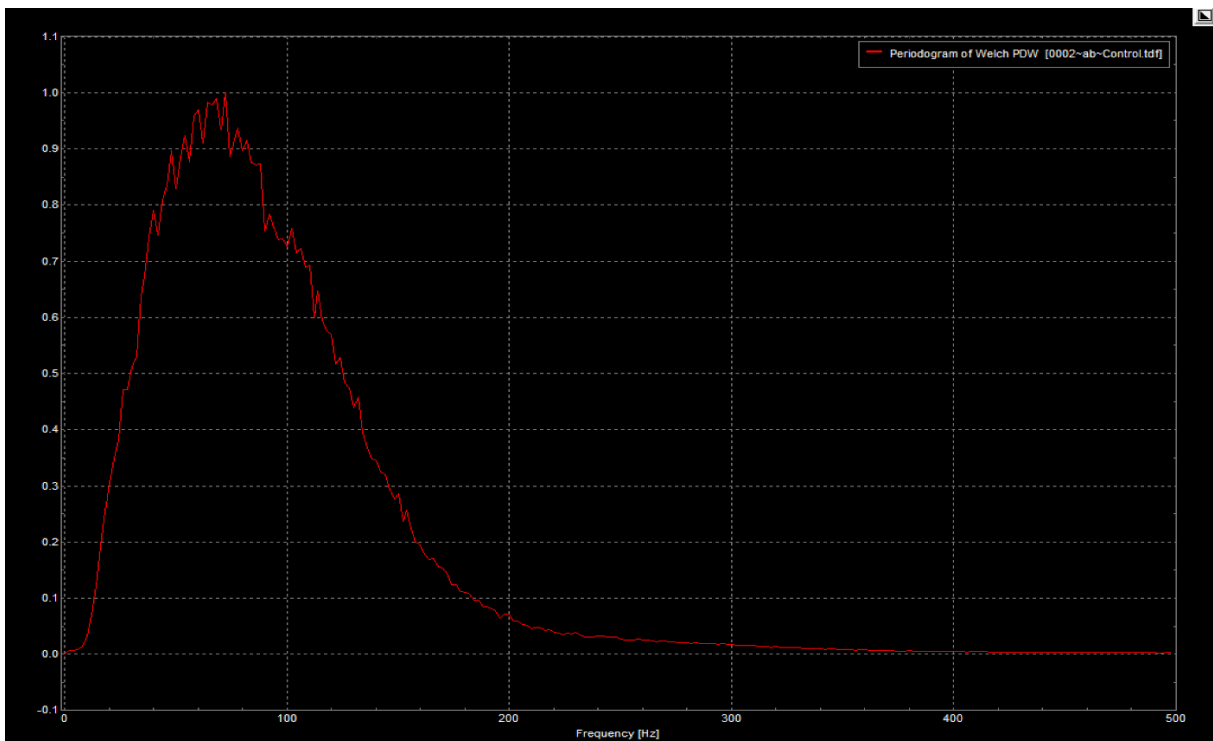
Processing

Appendix F Signal analysis of signal quality

Discrete Fourier transform (DFT) and Periodogram of Welch (PDW) are used to visually confirm the normality of the distribution of frequency components in the signal and detect any noise or electrical artefacts that could impact signal quality.



DFT graph produced by BTS Smart-Analyzer software.



PDW graph produced by BTS Smart-Analyzer software.