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Evaluation of Subjective and Objective Workload of Forestry Professionals

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EVALUATION OF SUBJECTIVE AND OBJECTIVE WORKLOAD OF FORESTRY PROFESSIONALS

A Thesis
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
Forest Resources

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by
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ABSTRACT

The Southern United States accounts for about 40% of the productive timberland of the country and is known as the wood basket of the United States. Timber logging is an important contributor to South Carolina's economy. Feller-buncher, skidder and loader operators play a vital role in the timber industry of South Carolina. However, their job is far from easy, especially as there are only a few members of a logging crew. They have to operate complex heavy machinery in challenging terrains while ensuring the efficient harvesting of timber, which demands extraordinary skills, precision, and better decision-making, leading to excessive mental and physical strain. Fire management also plays an important role in forest management in South Carolina. The forest fire professionals, including private contractors, state/federal agency personnel, or landowners, have to work under demanding conditions for long hours while controlling and fighting fires. In this study, the subjective workload of both forest equipment operators and forest fire professionals was studied utilizing the NASA Task Load Index. In addition, we observed the heart rate of equipment operators to study the activities causing excessive physical and mental workload. Our findings indicated that there is no significant difference in the overall workload of equipment operators working at clearcut and thinning sites. The workload dimensions of Effort and Frustration contributed the most to the overall workload, while Performance had the least contribution to the overall workload of the logging equipment operators. Sudden heart rate spikes occurred when operators conducted physical activities such as clearing debris from a felling head, trimming branches from the logs loaded to the log truck or loading logs to the log truck. For the forest fire professionals, there was no statistically significant difference in the self-reported workload of the fire workers working in prescribed fires and wildfires. When all workload data were combined, the workload dimensions of Effort, Physical Demand, and Mental Demand contributed the most to the overall workload, while Performance contributed the least. A high workload of forest fire professionals will eventually lead to an increased risk of accidents and a reduction in productivity. Understanding and managing workload is not only about ensuring the health and happiness of our workforce, but it's also about safeguarding the sustainability of our timber resources.

Keywords: Mental Workload, Physical Workload, NASA TLX, Heart Rate, Forest Operations, Wildfire, Prescribed Fire

DEDICATION

I dedicate this thesis to my parents (Mapatunage Karunarathna and Monika Bamunusinghe), my brother (Hemal), my sister-in-law (Dasuni) and my whole family and friends. Their unwavering love, support and guidance have been my guiding light throughout this journey.

This thesis resembles an important milestone in my journey, and I dedicate it to everyone committed to achieving their life goals.

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INTRODUCTION

0.1 Justification and Aim

Forest operations differ according to the activities conducted, such as felling, skidding, and delimbing. However, various types of machinery are available to perform these complex tasks efficiently (Melemez and Tunay 2010). In the southern United States, logging groups commonly conduct harvesting using mechanized equipment like grapple skidders and feller-bunchers (Wang et al. 2004). The southeastern logging operations are considered one of the most productive logging businesses in the entire U.S., as their annual production rates were seven times greater than the other regions of the U.S. (Conrad et al. 2018a). Logging plays a significant role in the economy in the Southeastern United States by providing jobs (Greene et al. 2001).

The human body is not created to do too much excessive work. Therefore, it requires technological advances to complete heavy work (Melemez and Tunay 2010). The harvesting practices using logging equipment such as feller-buncher/grapple skidder have become popular over the use of chainsaw systems in the industry for the past 25 years. The use of woodchippers has also increased over the past ten years with the emerging markets (Conrad et al. 2018b). Therefore, using more complex logging equipment has become prominent in the southern United States, including South Carolina. This was identified to reduce the physical workload of loggers. Even though using heavy machinery for forest operations is more efficient, utilizing these types of equipment is more complex (Szewczyk et al. 2020). When a person's workload is incompatible with their working capacity, it leads to work-related stress (Cinaz et al. 2013). Therefore, it is important to evaluate the workload of the forest equipment operators who are working with heavy machinery for long periods under demanding conditions.

Fires are crucial in hazard reduction, forest management practices, and ecosystem conservation (Weber and Taylor 1992). Prescribed fires and wildfires play a vital role in ecosystems of the Southern United States (Korhonen 2023; National Interagency Coordination Center 2023), and due to these fire occasions, plant species grown in these forests adapted to fire over time (Brenda et al. 2021; Weise 2023). Wildland firefighters around the world face an increased demand due to the risk of longer and more frequent fires (Phillips et al. 2012). Examining the workload associated with controlling wildfires and prescribed fires is crucial for both the preservation of natural resources and the safety of firefighters in their line of duty (Apud and Meyer 2011). To control fires, wildland firefighters must work lengthy shifts under challenging conditions (Navarro 2020). The state of the site, the types of fuel that burn, how the work is organized, how many firefighters are in a crew, where an employee is located on a fireline, what the allocation and rotation of breaks, and the climate condition at the site contribute to the workload of the firefighters (Apud and Meyer 2011).

Elevated occupational stress can have serious side effects on a worker, leading to physical and mental exhaustion, reduced focus on tasks, memory loss, errors in judgment, depression, frequent absence at work, repetitive accidental injuries, reduced productivity, and higher work-related costs (Hill 2000). Assessing the workload of forest workers is crucial to prevent them from having occupational health issues. Two main types of workloads have gained global attention in research: mental and physical workloads. Mental workload differs from physical workload as it focuses on the stress induced by the task demand. In contrast, the physical workload focuses on the physical stress experienced by the human body (Young et al. 2015).

0.2 Problem Statement

Workload is a crucial factor to measure in order to safeguard the health and safety of forest professionals. Even though there are studies conducted worldwide on workload in different sectors, studies done in the forestry sector are limited, especially in the United States. There are only a handful of studies done worldwide on the mental workload of logging equipment operators. Most workload studies in forestry have been conducted in Europe, including assessing workload in motor-manual harvesting conducted in Greece, Sweden and in Turkey ((Gallis 2006; Rehn et al. 2009; Çalişkan and Çağlar 2010). The mental workload of harvester operators was studied in Sweden, Poland, and Italy (Gellerstedt 2002; Spinelli et al. 2020; Szewczyk et al. 2020; Naskrent et al. 2022). In the United States, the workload-related studies conducted so far have evaluated the heart rate response for forest harvesting during summer (Smith et al. 1985), the impact of extended working hours on musculoskeletal disorders among logging equipment operators (Lynch et al. 2014), the exposure of loggers to vibration and noise due to equipment operation (Neitzel and Yost 2002), and the perspective of using exoskeletons to increase worker safety and health in forest operations (Kim and Chung 2023). Some of these studies have identified that logging equipment operators face both physical and mental workloads under different operating conditions. There is a gap in workload assessments in the United States for logging equipment operators, particularly for wheeled feller-buncher, grapple skidder and loader equipment operators.

Given the fact that forest firefighters work under challenging conditions, it is important to assess their workload. However, there were very few workload assessments conducted for forest firefighters, and the mental workload assessments are yet to be done. Studies have been conducted to identify the tasks that are physically demanding during bushfire suppression in rural Australia (Phillips et al. 2012), to identify the environmental factors affecting the workload of forest firefighters in Chile (Apud and Meyer 2011) and to understand the work pressure of firefighters in New Zealand (Parker et al. 2017). There were no workload assessments on forest firefighters reported from the United States. Therefore, it is important to initiate these assessments to safeguard the occupational health and safety of forest firefighters in the United States. Since the southern United States conducts the majority of annual prescribed burnings and wildfires, assessing the workload of forest fire professionals is crucial.

0.3 Thesis Scope, Goal and Structure

This thesis incorporates both subjective and objective measurements of workload carried out to understand the workload of logging equipment operators and fire professionals in the Southern United States. Chapter 1 of the thesis provides an overview of the workload research done so far in the forest operations sector in the US and worldwide. There are limited studies on the workload of logging equipment operators, particularly for the feller-buncher, skidder, and loader harvesting methods primarily utilized in the southern United States. Chapter 1 aims to provide an overview of the research that has been done thus far and to pinpoint the areas that still require investigation in order to measure the workload associated with forest activities accurately.

Chapter 2 of this thesis used the NASA Task Load Index to self-evaluate the workload. Interviews were conducted at the site for the logging equipment operators. Both heart rates of the logging equipment operators and video recordings of operator activities were collected for feller-buncher, skidder and loader operators. These data were used to observe the variations in heart rate with the specific activities conducted by the logging equipment operators. The study was conducted in seven logging sites in South Carolina as a proxy for southern US loggers. The goal of this study is to conduct an initial assessment of the workload of wheeled feller-buncher, grapple skidder and knuckle-boom loader operators working in the forests of the southern US.

Chapter 3 comprises the workload measurement of fire professionals using a Qualtrics survey, which included the NASA Task Load index. The survey gathers information about workload based on the respondents' prescribed fire and wildfire experiences. The workload of fire professionals is an area that was not given much attention. However, with the challenging work conditions, it is important to understand the work pressure to prevent health hazards. The goal of this study is to provide an initial assessment of the workload of forest fire professionals working in North Carolina and South Carolina.

0.4 Thesis Objectives

The overall goal of the thesis is to assess and document the workload in forest operations and forest fire control in the Southern United States. The specific objectives are to,

i) Provide a literature review of the studies conducted to evaluate the workload of logging equipment operators, summarizing global workload evaluation studies in forest operations and identifying future research needs in forest operations-related workload.

ii) Provide an initial assessment of the workload of logging equipment operators during timber harvesting operations while operating conventional wheeled feller-buncher, grapple skidder, and knuckle-boom loader harvesting systems in South Carolina.

iii) Provide an initial assessment of the workload of forest fire workers in the southern United States by assessing the subjective workload of forest fire workers working in prescribed fires and wildfires in North and South Carolina.

CHAPTER ONE

A REVIEW OF WORKLOAD STUDIES AND THEIR UTILIZATION IN FOREST OPERATIONS RESEARCH

Abstract

Human operators have a limited capacity to process information and react efficiently. Workload refers to the maximum capacity an operator requires to complete a task successfully. Forest operations involve using heavy, complex equipment that can increase the loggers' workload. Chainsaw operators have experienced a higher physical workload, mainly due to vibration and noise. With the mechanization of work, equipment operators now have less physical workload but a higher mental workload. To identify these physiological and psychological limitations of the workload of humans, it is important to study workload. Several methods have been developed to study workload. They are mainly subjective methods and objective methods. The subjective methods consist of surveys with questionnaires or rating scales, which the workers can self-evaluate. NASA Task Load Index, Chalder Fatigue Scale, and Nordic Standardized Questionnaire are examples of subjective methods. Objective methods consist of measures of the physiological changes that occur in response to the workload. Heart rate, heart rate variability, oxygen consumption, eye movement tracking and brain function analysis are some objective methods. Even though forest equipment operators have to work with complex interfaces in secluded forest sites, studies conducted to determine their workload are limited. Several studies have been performed worldwide about the physical workload of equipment operators. However, only

a few have studied the mental workload. This literature review focuses on exploring global workload studies, highlighting research gaps.

1.1 Background

Workload is becoming an important area of study for all occupations. While the ultimate goal of the companies is to maximize profits, the workers are focused on minimizing their workload while trying to achieve their targets (Miller 2019). Jobs with high demand and few resources were identified to negatively affect employees' physical and mental health, especially when there are fewer rewards (Vegchel et al. 2001; Bakker et al. 2010; Calnan et al. 2010; Heuven et al. 2010). Therefore, they require technological advances to complete heavy work (Melemez and Tunay 2010). Most physical workloads done by workers were gradually replaced with machines that reduce the workload on humans (Miller 2019). However, in forestry, it was identified that shifting from physically tiresome motor manual forest logging to fully mechanized logging can also cause an increase in the mental demand of machine operators (Heinimann 2007). Forest logging is considered one of the most hazardous occupations in the world (Holman et al. 1987; Slappendel et al. 1993). Several factors were identified that can increase the workload of forest loggers, such as the machinery and tools used, the personality of the loggers, organization characteristics and the characteristics in the physical environment, such as weather conditions (Slappendel et al. 1993; Shemwetta et al. 2002).

Even though there are studies conducted worldwide on workload, the number of studies done in the United States is limited, especially for logging equipment operators. Moreover, there are only a handful of studies done on the mental workload of logging equipment operators.

Therefore, this literature review on the workload of logging equipment operators will provide a comprehensive report about their workload, especially about the mental workload and the variables affecting it. The mental workload can vary from person to person, and with the site conditions, the different types of machinery used for logging. The precision of data for each study can vary depending on the method used to measure the workload.

This study aims to provide a literature review of the studies conducted to evaluate the workload of logging equipment operators with the objective of summarizing global workload evaluation studies in forest operations and identifying future research needs in forest operations.

1.2 Methodology

To identify sources for the literature review, I used two main databases, Google Scholar and Web of Science (WoS), and determined the types of articles available on the workload of forest equipment operators. Initially, we established much broader search terms, such as "stress and heart rate, stress and heart rate variability, workload and heart rate, mental workload and NASA TLX, logging equipment operators and mental workload, logging equipment operators and physical workload, mental workload and cortisol concentration, mental workload, and brain wave analysis" to obtain a list of research articles on evaluating workload of forest equipment operators, especially on mental workload.

From the available sources, I screened 20 most suitable research articles. They were sorted according to the harvesting method used by the equipment operators, the method used to measure the workload, different stand conditions and different regions of the world. Finally, I reviewed the selected studies to identify knowledge gaps and determine where further research is needed to ensure a healthy working environment for forest equipment operators.

1.3 What is Workload?

The capacity of human operators to process and respond to a task efficiently is limited, and workload is the maximum capacity a human operator requires to complete a task successfully. It is a balance between the resources required to complete a task and the resources that the operator can provide. If the demands exceed the limit of the capacity of the human operator, it can result in diminished performance due to overload (Gopher and Donchin 1986; O'Donnell and Eggemeier 1986; Wickens and Tsang 2015). The workload imposed on an operator refers to a situation encountered by that worker (Melemez and Tunay 2010). Some other definitions for workload have referred to it as work stress; sometimes, it is also referred to as fatigue (Hagen et al. 1998; Grzywiński and Hołota 2006). Another definition says workload is a human operator's effort to accomplish a task (Gawron 2019). According to this definition, it results from the interaction between a specific task (identified as the "task load," which can be described as the memory load of the tasks per unit of time) and the performer's insight about the level of effort necessary to complete this task load (Boehm-Davis et al. 2015; Gore 2017). Fatigue occurs due to excessive effort caused by physical or mental activity.

The workload concept was initially developed for use in aviation contexts; workload metrics and approaches have been adapted to other highly procedural areas to look at jobs that are finished in short amounts of time (Gore 2017). Later, workload studies were conducted in other fields, such as medicine, manufacturing industries, and construction, to determine the excessive workload for workers and to provide solutions to minimize it. Mental fatigue affects people working in many fields, such as the transportation (Itoh et al. 2000), construction (Li et al. 2020) and healthcare (Schlosser et al. 2012; Nilsen et al. 2019) sectors. When work-related stress becomes overwhelming, it may negatively affect the worker's body and mind, and it ultimately can result in an injury or an accident (Lotfalian et al. 2012). High levels of occupational stress can have serious side effects on a worker, including physical and mental exhaustion, a lack of focus, memory loss, mistakes in judgment, self-physical exploitation, depression, frequent absences, repetitive accidental injury, low productivity, and increased work costs (Hill 2000).

The workload must be accurately measured and quantified to be managed appropriately (Gore 2017). Occupational safety is a world-renowned law with widespread implications that ensure the physical and mental safety of workers of every occupation type (Lotfalian et al. 2012). Identifying the workload of workers is important to prevent them from having occupational health issues. Two main types of workloads have gained global attention: mental and physical. Mental workload is distinct from physical workload as the mental workload is fixated on the stress caused by the task demand. In contrast, the physical workload is fixated on the physical stress the human body experiences (Young et al. 2015). The physical workload is the musculoskeletal strain of workers when they overwork. Nowadays, machines that do most of the heavy work replace most of the physically tiresome work. Workload studies have shifted from physical to other types of workloads, such as psychomotor, communication, and perceptual workload (Wierwille et al. 1985). With the mechanization of work, the frequent use of technology can impose high cognitive demand on workers, making researchers more interested in studying mental workload (Spinelli et al. 2020; Bafna and Hansen 2021). A comparison between mental and physical workload was made that says each has two factors: stress and strain; stress means the task demands, and strain implies the impact on the person (Schlegel 1993)

1.3.1 Physical Workload

Excessive physical workload can cause work-related musculoskeletal disorders (Hansson et al. 2009; López-Aragón et al. 2017). Musculoskeletal Disorders (MSDs) are a health problem of major significance in most of the industrialized world. Musculoskeletal health issues arise when the mechanical strain surpasses the capacity of the locomotor system of the human body to withstand it. The Bureau of Labor Statistics has categorized the general illnesses and disorders of the musculoskeletal system or connective tissues as MSDs (López-Aragón et al. 2017). Frequently, this happens when employees carry or handle heavy loads in the wrong postures or engage in repetitive activities, and their ability to meet the task's requirements (including physical, psychosocial, environmental, and cognitive demands) is not sufficient due to their interactions with their surroundings (López-Aragón et al. 2017).

The relationship between MSDs and occupation has been investigated in numerous studies. MSDs have traditionally been linked to physical factors at work, such as poor posture, movements and vigorous efforts required to fulfill the task (Stanton et al. 2005). However, the relationship between psychosocial work environment and MSDs has come increasingly into focus (Baek et al. 2018). MSDs are identified as a primary cause for absence at the workplace, and they represent a substantial financial burden for a country due to health care costs (Gallis 2006). MSDs are also known as a significant health problem causing disability and other long-term health problems (López-Aragón et al. 2017). The Bureau of Labor Statistics defines MSDs as a pinched nerve, herniated disc or a torn meniscus; sprains, swellings or tears; hernia, pain, swelling, tumescence; carpal or tarsal tunnel syndrome; Raynaud syndrome; and general illnesses and disorders of the musculoskeletal system or connective tissue (López-Aragón et al. 2017).

Providing a good work environment and safety gear is the primary method to achieve the optimum physical performance of workers (Shemwetta et al. 2002). Studies show that providing adequate food and fluid to the workers and taking short breaks can optimize their productivity, reduce physical workload, and reduce the hazard ratio during a workday (Çalişkan and Çağlar 2010). Although we cannot change or make improvements in the human body to do an excessive amount of work, there are many technological improvements to conduct activities causing excess physical workload (Melemez and Tunay 2010).

1.3.2 Mental Workload

Mental workload can consist of two components: stress (task demand) and strain (the impact upon the worker) (Stanton et al. 2005). Cognitive demand is the level of focus necessary to fulfill a task to the required performance standard that can be influenced by factors such as external support and the experience of the performer (Stanton and Young 2001; Stanton et al. 2005). Daily use of technology may impose high cognitive demands that develop over time as people have to work with complex interfaces and often work long hours under demanding conditions, staying focused to avoid accidents (Spinelli et al. 2020; Bafna and Hansen 2021). Due to increased error rates, tiredness, decreased motivation, increased reaction times, and cognitive tunneling, excessive mental workload can threaten users' performance and their safety (Thomas and Wickens 2001; Dehais et al. 2013; Dixon et al. 2013). Physiological parameters can be influenced by factors other than mental workload, such as physical exertion, which can impact the research outcomes. Consequently, it's crucial to distinguish between changes in physiological variables attributable to mental workload and those resulting from physical workload (Fibiger et al. 1986).

Mental fatigue can affect the productivity and the mental health of workers, decreasing their quality of life (Ricci et al. 2007; Bafna and Hansen 2021). If mental fatigue persists for an extended period, it can cause health problems such as chronic stress, depression, or burnout (Cinaz et al. 2013). Moreover, it may cause physical disorders such as hearing weakening and traumatic brain injuries (Bryant et al. 2004; Wang et al. 2017). It is important to take countermeasures to mitigate the increased workload. These impacts of mental workload on the human body can be minimized by proper planning of the duration of the work shifts (Naskrent et al. 2022). Technology is improving daily, which can contribute significantly to mitigating workload through automation as it can help reduce operator’s responsibilities at work (Cottrell and Barton 2013).

1.4 Methods of Measuring Workload

Measuring workload is an important concept to study. It is the method to describe variations in workload felt upon humans with regard to their ability to process information and create responses to the workload (Gopher and Braune 1984; Miller 2019). The approaches to measuring workload have changed throughout time. There are subjective and objective/physiological techniques to measure the workload (Figure 1). The objective methods are based on continuous monitoring of changes in the body (Miller 2019).

Subjective measures are taken using questionnaires usually asked to be answered by the participants, and they include scales and rankings used to measure the amount of workload. Subjective workload measuring techniques are developed to measure both physical and mental workload. For instance, the Nordic Standardized questionnaire and Chalder Fatigue Scale are used to measure physical workload, while the NASA Task Load Index (NASA TLX) and Subjective Workload Assessment Technique (SWAT) are used to measure the overall workload (Hart and Staveland 1988; Hill et al. 1992). Heart rate, heart rate variability (HRV), blood oxygen demand, eye tracking, salivary cortisol level measures and brain wave analysis are objective measures of workload. Objective methods such as HRV, eye movement tracking, salivary cortisol level and brain activity analysis are popular techniques used to assess mental workload (Aghajani et al. 2017; Spinelli et al. 2020; Naskrent et al. 2022), while heart rate and oxygen consumption indices are frequently used to assess the physical workload (Hagen et al. 1993; Kirk and Sullman 2001; Çalişkan and Çağlar 2010).

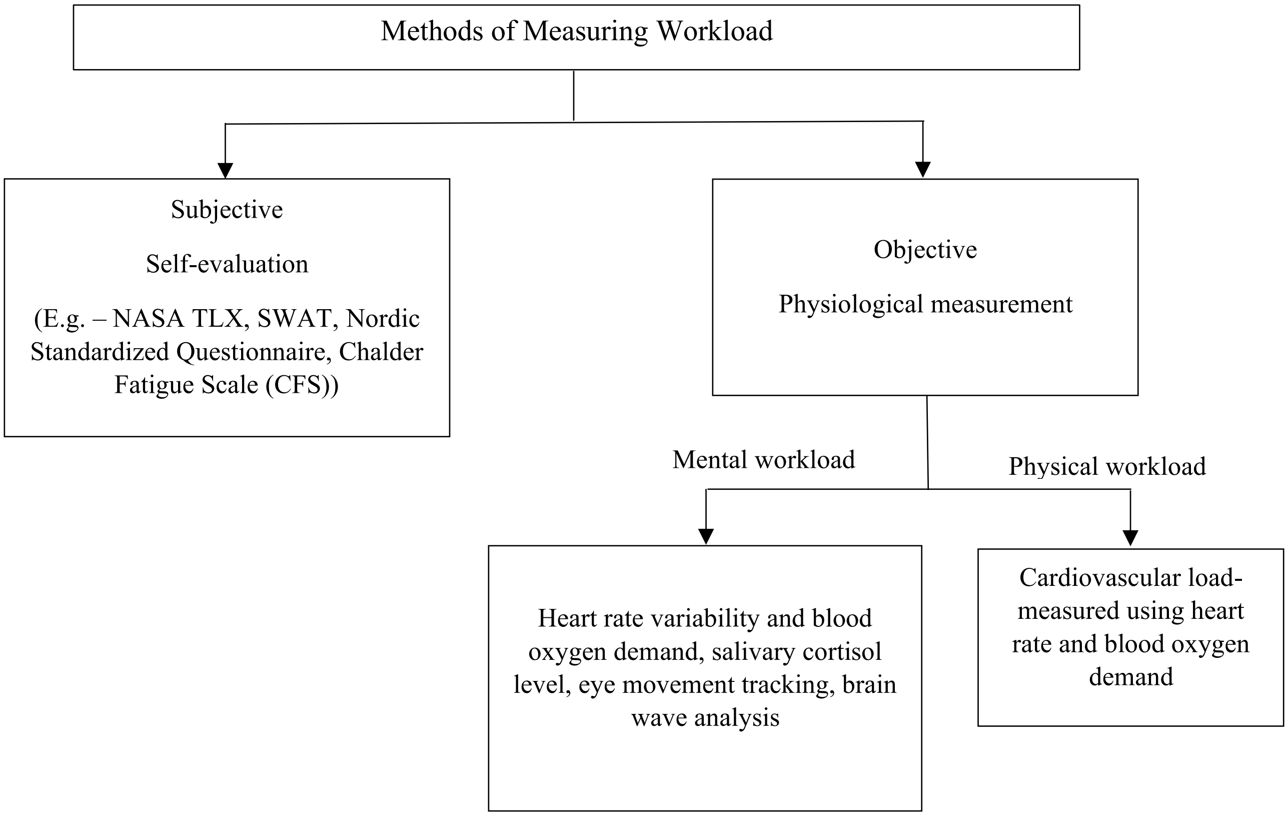

Figure 1. 1: Flowchart of the methods of measuring workload

1.4.1 Subjective Methods

Different questionnaires were developed to measure subjective workload, and the workers were asked to self-evaluate the workload they experienced during work. These questionnaires can consist of questions or scales to rate the workload. Some of the most commonly used subjective methods to measure workload are the NASA TLX, the Nordic Standardized Questionnaire, and the Chalder Fatigue Scale (CFS).

There are different definitions for fatigue. While some definitions attempt to pinpoint the cause of fatigue (such as muscle dysfunction), others take a behavioral approach and regard it as a cause of performance decline (Chalder et al. 1993). Requests have been made for better methodological research of the epidemiology and symptomatology of fatigue and for more accurate operational case definitions (David et al. 1990). In the past, the majority of fatigue questionnaires for specific research were developed mainly to measure workload (De Vries et al. 2003).

1.4.1.1 Chalder Fatigue Scale

This is a self-evaluating questionnaire that was initially developed to measure the chronic fatigue of the clinical populations (Chalder et al. 1993). However, this questionnaire has been revised and is now used in both clinical and non-clinical studies to measure fatigue. The questionnaire has 14 items, which were mainly divided into two dimensions physical fatigue and mental fatigue. The revised questionnaire has 11 items, with three items dropped. For each item in the questionnaire, the participant has to select from “Better than usual, No worse than usual, Worse than usual, and Much worse than usual.” There are two scoring systems that can be used in the scale. In the Bimodal method, respondents give either 1 or 0 as a score, giving a maximum of 11 for all items in total. In the Likert method, respondents give a score of 0 to 3, giving a maximum of 33. The bimodal method counts the symptoms, while the Likert method weighs the intensity of the symptoms (Chalder et al. 1993; Goudsmit et al. 2008). The authors established that a global binary fatigue score of 3 or less represents scores of those who are not fatigued, with scores of 4 or more equating to ‘severe fatigue’ (Jackson 2015). The participants are asked to self-evaluate the questionnaire. The items in the questionnaire are about sensations and functionality rather than their beliefs and opinions about health status (Jackson 2015). The 14 items in the Chalder Fatigue Scale are listed below in Table 1.1.

Table 1. 1: The 14-item Chalder-Fatigue Scale (Chalder et al. 1993)

Item no.	**Item**
Physical fatigue symptoms	
1	Do you have problems with tiredness?
2	Do you need to rest more?
3	Do you feel sleepy or drowsy?
4	Do you have problems starting things?
5	Do you start things without difficulty but get weak as you go on?
6	Are you lacking in energy?
7	Do you have less strength in your muscles?
8	Do you feel weak?
Mental fatigue symptoms	
9	Do you have difficulty concentrating?
10	Do you have problems thinking clearly?
11	Do you make slips of the tongue when speaking?
12	Do you find it more difficult to find the correct word?
13	How is your memory?
14	Have you lost interest in the things you used to do?

1.4.1.2 Nordic Standardized Questionnaire

This questionnaire is recognized and validated internationally and is used to identify and record the symptoms related to musculoskeletal disorders (López-Aragón et al. 2017). The questionnaire consists of yes/ no questions related to symptoms of 9 parts of the human body during the last 12 months and last 7 days (neck, shoulders, upper back, lower back, elbows, wrists/hands, hips, knees, and ankles/feet). The questionnaire asks if the subject has had any trouble such as aches, pain, discomfort or numbness during the last 12 months if the subject has been prevented from carrying out normal activities such as job, housework or hobbies due to this trouble, whether the subject has seen a physician due to this condition, and if the subject has had any trouble during the last seven days (Franasiak et al. 2014). The original questionnaire only identified the symptoms and the studied population percentage who are with these symptoms. Dickinson (1998) has identified some limitations in the original questionnaire and has suggested including the severity (effect on the person) and the extent of disability. Studies have already been conducted using the Nordic Standardized Questionnaire in several sectors, including medicine and forestry (López-Aragón et al. 2017).

1.4.1.3 NASA Task Load Index (NASA TLX)

The NASA Task Load Index (NASA TLX) was developed by the NASA Human Research Center to measure the workload under six parameters identified as primary factors of workload: physical demand, mental demand, temporal demand, effort, performance, and frustration (NASA Ames Research Center 1986). NASA TLX is a multi-dimensional method of ranking. It gives an overall score for the workload based on a weighted average of ratings on these six dimensions identified to affect the workload (Hart 2006). A pairwise comparison of the 6 dimensions is done to calculate the weight of each dimension, which gives the degree to which each dimension contributes to the overall workload. The subject is asked to select one from each pair and then tally the total number of times each dimension is selected which can range from 0-5. The second part of the NASA TLX gives a numerical rating to the six dimensions, and the rating scale ranges from low to high (0 to 100). These rating scales provide the magnitude of each dimension each operator felt during the task completion (NASA Ames Research Center 1986).

The NASA TLX was tested for different occupations in different situations, from simulated flights and supervisory control simulations to laboratory tasks while it was being developed

(Hart 2006). NASA TLX was first developed to evaluate workload in the aviation sector (Hart 2006). After that, NASA TLX was mostly used in the military, especially for soldiers, armored vehicles in command and control, power plants, robotics, unmanned vehicles, and teleoperation and space applications (Hart 2006). In the later years, NASA TLX was utilized for studies in the medical sector, automobile driving, and the use of computers and other portable technological devices (Hart 2006).

1.4.2 Objective Methods

The objective method of measuring workload differs from subjective methods, as it consists of physiological measurements related to physical or mental workload. Physiological measures primarily measure continuous reactions of the body in response to the workload, such as sudden changes in respiration, eye activity, cardiac activity, speech measures, and brain activity (Shriram et al. 2012). Usually, the physical workload is measured as the cardiovascular load (Ilmarinen 1984). If the task needs more energy, more oxygen is required, which causes an increase in the heart rate to pump more oxygenated blood to the muscles (Andersen et al. 1978). These parameters help to measure metabolic energy consumption (Roja 2005; Rehn et al. 2009). Thus, the physical workload can be estimated by comparing heart rates measured at rest and while working (Shemwetta et al. 2002) and using oxygen consumption (Ilmarinen 1984). Thus, heart rate and oxygen consumption are physiological measures used to determine physical workload. In a stressful situation, the autonomic nervous system suppresses the parasympathetic nervous system and activates the sympathetic nervous system, causing the release of stress hormones adrenaline and noradrenaline (Taelman et al. 2008). These hormones transport glucose and fat to the body's muscles, which are the energy sources of the human body; the oxygen demand and heart rate will increase, raising blood pressure and reducing HRV (Berger 2003). Thus, HRV, stress hormone concentration in blood, eye movement tracking, and brain activity analysis are used to obtain physiological measures of mental workload.

1.4.2.1 Heart Rate

Efforts to measure heart rate (i.e., taking the pulse) have proven to be one of the most useful ways to assess cardiovascular load as it can be done very easily (Shemwetta et al. 2002). If the physical workload is excessive, more and more energy is needed to complete the task. The energy that is generated by the aerobic combustion of food is transformed into the muscles using oxygen (Shemwetta et al. 2002; Çalişkan and Çağlar 2010). The relative heart rate (HRR) at work is an indicator of the physiological capacity of workers. It was used as a reference to measure the physiological workload in the forestry sector (Apud et al. 1989). The number of heartbeats per minute is determined, and a wearable heart rate sensor such as a chest belt ((Çalişkan and Çağlar 2010) or as an armband (Goodie et al. 2000) is used to measure physical workload. When this device is attached to the chest or arm, it collects heartbeats per a given time to calculate heart rate and broadcast it to an application installed on an electronic device. By using this device, we can collect resting heart rate (HR_{rest}) and the heart rate at work (HR_{work}), which is used to calculate relative heart rate (HRR) (Arman et al. 2021). A range of 30-40% HRR suggests the capacity to work for eight hours without experiencing fatigue (Kirk and Parker 1996).

1.4.2.2 Blood Oxygen Demand

An elevated heart rate is closely associated with oxygen demand (VO_2), with the heart rate increasing being directly proportional to the level of physical exertion (Çalişkan and Çağlar 2010). This is because the heart and the active muscles require more oxygen than relaxed muscles. Oxygen demand is the aerobic capacity of a person (Brighenti-Zogg et al. 2016) and is expressed as liters per minute (l/min) or as milliliters per minute (ml/min) (Çalişkan and Çağlar 2010). Heart rate sensors discussed above can be used to measure $VO_{2\ max}$, which is the maximum oxygen consumption. Oxygen consumption of the heart and the extent of labor are directly associated with the contraction ratio of the heart (Çalişkan and Çağlar 2010). Therefore, the parameters, heart rate, and oxygen consumption determine the metabolic energy consumption (Roja 2005; Rehn et al. 2009).

1.4.2.3 Heart Rate Variability (HRV)

Heart rate variability can be used to measure mental workload. The release of stress hormones results in the narrowing of blood vessels, leading to elevated blood pressure, heightened muscle tension, and alterations in both heart rate (HR) and HRV. HRV, also called the RR interval time series, is derived from the tachogram. This is the gap between two successive R peaks (heart rate peaks), which is measured in time (Taelman et al. 2008). In the study conducted by (Taelman et al. 2008), they measured HRV as the variance in time between two successive R-peaks obtained through an electrocardiogram ECG. The results showed that the mean RR while conducting a mental task (0.790 ms) was significantly lower than the mean RR at rest (0.816 ms).

1.4.2.4 Hormone Level Changes

Numerous hormonal changes have been observed due to physical workload and cognitive demand (Haggendal et al. 1970; Fibiger et al. 1986). Biochemical markers are a cost-effective alternative to other objective measures of mental workload, such as electroencephalography (EEG). They do not disrupt the worker's normal routine, do not demand specific expertise for implementation, and are straightforward to put into practice (Zoaktafi et al. 2020). The hormones adrenaline, noradrenaline, and cortisol are considered as biochemical indicators of mental workload (Fibiger et al. 1986). For studies, taking blood samples can be painful and create fear among participants, while taking salivary samples is much easier. Moreover, the results for measuring salivary cortisol levels were the same as plasma cortisol (Zoaktafi et al. 2020). Cortisol is a steroid hormone synthesized in the adrenal glands. It serves various roles, including regulating blood pressure and cardiovascular activities and controlling the metabolism of macronutrients (Mcgrady et al. 1987; Zoaktafi et al. 2020). When mental workload increases, the salivary cortisol concentration is observed to increase (Fibiger et al. 1986). Salivary samples were collected at different time periods in the study and experimented with to measure the cortisol concentration. However, no study has used salivary cortisol levels to measure the mental workload of forestry sector workers.

1.4.2.5 Eye Movement Tracking

Methods for measuring mental fatigue rely on assessing various mental and physical responses, including cognitive, emotional, and behavioral indicators. Eye-tracking and electrooculography (Itoh et al. 2000; Hopstaken et al. 2015; Tag et al. 2019) have become more popular in measuring mental workload due to the improved accuracy and durability of lightweight equipment available in the market (Barz et al. 2018; Hu and Lodewijks 2020). These technologies can be effectively utilized for objective and ongoing evaluations of mental fatigue. The eye-related characteristics are classified into the following eye metric groups: pupil size, percentage of eye closure, blink frequency, saccades, fixations, microsaccades, ocular drift, and eye movement activity (Bafna and Hansen 2021). Fixations are occurrences when an individual's gaze briefly pauses or focuses at one point for a short time (Naskrent et al. 2022). According to Cowen et al. (2002) the duration of fixational gaze on an observed object can range from 0.2 to 0.3 seconds. Saccades refer to swift eye movements that occur while transitioning between fixation points. Numerous studies have suggested that pupil dilation could serve as an indicator of the progression of fatigue, as the size of the pupil tends to increase as cognitive strain intensifies (Hoeks and Levelt 1993; Goldberg et al. 2002). Mobile eye-tracking devices are commonly used to study eye movements (Renata et al. 2018; Naskrent et al. 2022).

1.4.2.6 Brain Activity Analysis

Electroencephalography (EEG) has been used to assess mental workload based on brain function after a large number of studies employing EEG for developing Brain-Machine Interfaces (BMI) (Aghajani et al. 2017). Other than EEG, magnetoencephalography (MEG), functional magnetic resonance imaging (fMRI), and functional near-infrared spectroscopy (fNIRS) are different techniques used to extract brain signals (Pandey et al. 2020). The brain contains billions of cells, with neurons accounting for half of them, while the rest support the functions of these neurons. The electrical signals generated by the brain can be detected using EEG, which involves placing electrodes on the scalp. These EEG electrodes are typically integrated into washable, flexible caps, streamlining the electrode application process and enabling consistent data collection from the exact scalp locations when studying multiple participants. This convenience and reliability make EEG a widely favored and effective method for assessing mental workload (Pandey et al. 2020).

A more recent technique, functional near-infrared spectroscopy (fNIRS), has demonstrated potential in Brain-Computer Interfaces (BCI) applications for differentiating between motor tasks (Naseer and Hong 2015). Using both EEG and fNIRS simultaneously, referred to as EEG+fNIRS, is believed to be more reliable as a practical technique that offers greater accuracy compared to each modality used separately. The fNIRS method is complementary to EEG by monitoring changes in cerebral blood flow (CBF) and related hemoglobin concentrations measured using near-infrared light sensors/ detectors on the scalp. Moreover, fNIRS does not have electromyographic (EMG) and blink artifacts and exhibits a close correlation with the blood oxygen level-dependent (BOLD) signal obtained from functional magnetic resonance imaging (fMRI) (Strangman et al. 2002; Huppert et al. 2006). In fNIRS (functional Near-Infrared Spectroscopy), a process involves directing near-infrared light through the scalp and skull, allowing it to penetrate the brain. The intensity of the light that scatters within the brain is then recorded. When the brain responds to a stimulus, neural activity increases, enhancing blood flow in the activated region. This altered blood flow results in an increase in blood volume, which can be evaluated by measuring the concentrations of oxyhemoglobin (HbO), deoxyhemoglobin (HbR), or the combined total (HbT). Typically, during cortical activation, the levels of HbO rise while HbR levels decline (Chance et al. 1993; Hoshi and Tamura 1993; Kato et al. 1993; Villringer et al. 1993). The variation in light intensity when a stimulus is presented contrasts with the light intensity during a baseline event when either no stimulus or a control stimulus is introduced. This change, compared to the baseline, yields insights into the hemodynamic response associated with brain activation (Gratton et al. 2001).

1.5 Limitations of Subjective and Objective Measurements

While some of the discussed techniques can be used to measure the overall workload, others can be used to measure either the physical or mental workload. For instance, NASA TLX is used to measure the workload as a multidimensional index that rates the Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, and Frustration felt by the person while performing the task (Hart and Staveland 1988; Hoonakker et al. 2011). It has also been used to evaluate mental workloads in some studies (Spinelli et al. 2020). Chalder fatigue scale is used to measure the severity of fatigue, including physical and mental fatigue (Jackson 2015). The Nordic Standardized Questionnaire is used to identify and record the symptoms related to musculoskeletal disorders related to work activities (López-Aragón et al. 2017). Physiological measures like heart rate and oxygen demand are used to evaluate the physical strain on workers (Rehn et al. 2009; Çalişkan and Çağlar 2010). HRV shows changes when performing mental tasks, so it was identified as a method to measure mental workload (Taelman et al. 2008). As eye-related characteristics show changes with mental strain, eye-tracking techniques are used to measure mental workload (Szewczyk et al. 2020; Naskrent et al. 2022). Hormonal changes in the body can be caused by both physical and mental workload (Haggendal et al. 1970; Fibiger et al. 1986). For instance, changes in salivary cortisol levels are used to measure mental workload (Fibiger et al. 1986).

Electroencephalography (EEG) has been used in studies assessing mental workload based on brain function (Aghajani et al. 2017).

Using these methods to study mental and physical workload has advantages and disadvantages. Chalder Fatigue Questionnaire (CFQ 11) has been widely utilized in research to measure fatigue. It performs incredibly well compared to other more extended and more comprehensive assessments (De Vries et al. 2003). Another advantage of using the Chalder Fatigue Scale is that it is commonly employed in occupational research, enabling easy comparisons across various studies and populations (Jackson 2015). There are several advantages to using the Nordic Standardized Questionnaire to evaluate the workload, such as the standardization of the questions, no charges related to the questionnaire, globally accepted, used as a self-evaluation, can apply to large populations, relatively quick identification of symptoms, and can use together with other evaluation methods too. However, there are some disadvantages related to the Nordic Standardized Questionnaire. They are challenging to identify the accuracy of the data provided (truthfulness of the responses), difficulty in use in countries that do not speak English due to misinterpretations and errors in translations, restriction of exhaustive questions only to 3 areas of the body, complexity in data analysis for large populations and the responses may differ according to the technician administering the questions (subjectivity) (López-Aragón et al. 2017). The advantage of using the NASA TLX method to evaluate workload is that it relies on subjective evaluation of workload, is simple to implement, and yields results while being non-invasive and capable of detecting changes in mental workload with sensitivity (Spinelli et al. 2020). In subjective methods, the answers can be biased according to the individual experiences and emotions of the participants of the study, and they can have a pre-defined concept about the workload, which makes their ratings biased. It is implausible for them to know the variables of their tasks and the process that causes their actions (Hart and Staveland 1988). One of the significant limitations of using self-evaluating methods is that it limits the depth researchers can dive into the research problem (Szewczyk et al. 2020). Since subjects can have different levels of emotions and definitions of workload, it is difficult to prevent its effect when they are filling out the questionnaire (Spinelli et al. 2020).

Utilizing physiological measurements offers several benefits. Physiological methods are useful when operator strategies are changed, and the subjective measures become insensitive (Cain 2007). For instance, data collection can be inconspicuous and won't disrupt primary tasks. These measurements can be standardized and compared across various studies, and they represent objective assessments, necessitating a relatively small sample size while delivering more precise assessments of mental workload (Lean and Shan 2012; Young et al. 2015; Charles and Nixon 2019). However, when using these physiological methods, there are some limitations. The equipment can be challenging to use in the field. For instance, according to Naskrent et al. (2022), the eye-tracking device is fragile even though it is portable and can be used in the field. They further suggest they are more suitable and thus limiting to use for research conducted in controlled environments. Meshkati et al. (1995) have stated that objective techniques are not used to measure the imposed workload but, in particular, give information about how subjects respond to the workload and how they cope with the workload. By studying several workload measuring methods in a simulator at NASA Ames, Corwin (1989) has identified some disadvantages of using physiological techniques. They are: eye movements are insensitive to the experimental manipulations, even though heart rate variability is sensitive to mental workload, but it can be affected by other effects too, and heart rate variability and blood pressure spectral analysis are insensitive to workload manipulations while subjective methods (NASA TLX and SWAT) proved to be reliable and valid (Meshkati et al. 1995).

1.6 Workload in Forest Operations

Logging activities require a considerable amount of physical energy, particularly with motor-manual operations. Harvesting is far more hazardous than any other forest operation (Melemez and Tunay 2010). Many developed countries, including the United States, use complex and expensive machinery for felling, delimbing, skidding, and loading purposes (Melemez and Tunay 2010) to reduce the physical workload of the loggers. There are several technical phases in the timber harvesting process in the United States, such as felling, skidding, delimbing, loading, and transporting them to the sawmill. In these different activities, workers spend considerable physical energy throughout the working day. Studies like Pasicott and Murphy (2013) show that most logging operations worldwide are mechanized, and motor-manual harvesting is practiced mainly in steep terrains. This is because mechanized harvesters significantly enhanced worker well-being and safety in contrast to the conventional method of manual tree felling (Bell 2002). Workload studies in forestry have been conducted predominantly in Europe, with fewer studies conducted in North America and other regions of the world. Some of these studies are discussed below. A summary of workload studies in Europe, North America and other regions is given in Table 1.2.

1.6.1 European Studies

Hagen et al. (1993) measured the physical workload of chainsaw operators working in forests in South-eastern Norway. The average heart rate measured during all work phases was 138±10 beats per minute for younger participants and 126±17 beats per minute for older participants. Furthermore, heart rates varied among different work phases and activities performed. The study also revealed slight but statistically significant associations between the amount of wood cut and both maximal oxygen consumption (in milliliters per kilogram per minute) and oxygen consumption (in milliliters per kilogram per minute) during work. They also measured the oxygen consumption during all phases of work, averaging 1.8±0.2 liters per minute (for younger participants) and 1.5±0.2 liters per minute (for older participants). This corresponded to approximately 49±4% of the estimated maximal oxygen consumption obtained from an ergometer bicycle exercise test for younger individuals and approximately 53±7% for older individuals (Hagen et al. 1993).

In a study of the musculoskeletal issues encountered by individuals working in forestry in Greece (Gallis 2006), the frequency of musculoskeletal symptoms was assessed using the Nordic Standardized Questionnaire. The research outcomes indicate that chainsaw operators in Greece are engaged in a profession that poses a significant risk of work-related musculoskeletal disorders. The results highlight that lower back issues are a prominent health concern, and there is a noticeable prevalence of discomfort in the neck, arms, and shoulders. Over the past year, eight of ten forest workers reported experiencing lower back problems: seven had issues with their hands/wrists, six with their knees, and five with their necks and shoulders. Additionally, three workers experienced discomfort in their elbows, upper back, feet/ankles, and thighs/hips, respectively (Gallis 2006). Grzywinski et al. (2022) studied the physiological workload of loggers (two teams consisting of two persons each) felling and forwarding in young Alder stands in Poland. They used heart rate indices to measure the energy expenditure during winter and summer. Heart rates of loggers during summer were 113.9 bpm and 109.0 bpm, and during winter, they were 128.6 bpm and 137.9 bpm. Heart rates for logger's assistants were also 123.1 bpm and 149.4 bpm in winter, and 113.9 bpm and 96.9 bpm in summer. Heart rates for loaders in winter were 124.7–154.9 bpm; in summer, they were 108.8–121.6 bpm. They found that the physical workload and energy expenditure for all jobs were significantly higher during winter than in summer.

In the study by Gellerstedt (1997), the strain of mechanized cleaning equipment operators in Swedish forests was evaluated. They have analyzed the work elements of these forestry machines with the workload of operators. The HRV of the operators was low at the beginning of their work shifts compared to the middle and end of the work shifts. Also, all three operators have stated that they have neck problems, and the job rotation helps them prevent taking sick leaves. They have agreed that pre-commercial thinning was an intensive mechanized forest operation.

Berger (2003) has evaluated the mental workload of the harvester operators working in Austrian forests. They studied the physiological processes that happen in the human body with stress and the associated health issues. HRV and psychological tests were used to identify single stress factors and to identify the combination of stress factors that have an impact on stressful situations. They have identified that the HRV of the harvester operators was very high during the whole day, and the physical fatigue was high during the evening of the workday compared to the morning.

Spinelli et al. (2020) studied the mental workload experienced by harvester operators in two different silvicultural systems in Germany: a pure conifer stand and a mixed wood stand. They monitored the performance and mental workload of 13 harvester operators when they were operating harvester simulators at two different virtual stands designed as a pure conifer stand and a mixed wood stand. They have used NASA TLX and HRV to evaluate the mental workload. The results of the subjective study confirmed an increase in Mental Demand, Frustration, and Effort of the operators when they were shifting from the pure conifer stand simulator to the mixed wood stand. However, the effects of the mixed wood and pure conifer treatment type on the mental workload were not reflected in the HRV analysis, mostly due to the small sample size.

In the study by Naskrent et al. (2022), Tobii Pro Glasses 2 mobile eye-tracker was used to collect data on the number and duration of saccades, frequency of saccades, the proportion of saccade time, mean pupil diameter during fixations, and the mean pupil diameter during saccades for 23 harvester operators working in clearcutting and late thinning sites in Poland. The results indicate an increased frequency of saccades in clearcutting areas both during daytime and nighttime which could imply an elevated mental strain due to the requirement of making multiple undercuts on trees. This reduces work efficiency and raises concerns about the potential risk of head damage or trees falling onto the machinery. It was found that, during both fixations and saccades, slightly larger average pupil sizes were observed during tree felling across all logging methods, except in the case of late thinning.

Szewczyk et al. (2020) conducted a study to assess the elevated mental workload of harvester operators caused by escalating slope inclinations in Italian forests. Data on eye activity were collected from a harvester operator operating in forest stands with average slope gradients of 9%, 23%, and 47%. Fixation time and frequency of fixation number were observed. As the slope gradient increased, the frequency of fixations during task execution rose, and so did the duration of these fixations. When working on a 23% slope, the average duration of saccades was 5% less than that observed during work on a 9% gradient. An even more significant reduction in saccade duration (approximately 22%) was noted when working on a 47% inclination. According to a study conducted in Sweden for harvester operators, the performance of the eye tracker was influenced by substantial head movements, alterations in lighting conditions, and potential vibrations (Häggström et al. 2015).

1.6.2 North American Studies

Smith et al. (1985) evaluated the heart rate response for forest harvesting work in the southeastern United States during summer. They determined the physical workload of the chainsaw, cable skidding, feller-buncher, grapple skidder and knuckle-boom loader operators who worked in forests in Alabama. The maximal oxygen consumption (VO_2 max) of the workers was between 28 and $53 ml min^{-1} kg^{-1}$. The percentage of task time that recorded heart rates higher than 120 bpm ranged from 42.5% to 69.2%. The study indicated that the manual and semi-mechanized tasks are potentially more stressful than the fully mechanized tasks. They further indicated that warm summer temperatures increase heart rates. A study was conducted recently to assess the workload of wheeled feller-buncher, grapple skidder and loader operators in South Carolina using NASA TLX and heart rates with video records to identify activities causing excessive workload. According to the findings, there was no significant difference between the workload at clearcut and thinning sites and the workload dimensions; Effort and Frustration contributed the most to the overall workload, while Performance had the least contribution. Sudden increases in heart rate were observed when operators were conducting physical activities such as clearing debris from the felling head or loading logs onto a log truck (Mapatunage et al. 2024).

Lynch et al. (2014) conducted a study about the impacts of extended working hours in the logging industry in the southeastern United States, assessing the musculoskeletal disorders and neck and back pain among logging equipment operators. There were several other studies conducted in the United States on the occupational safety of forestry professionals. However, they are not focusing on the workload of the forestry professionals. A study by Neitzel and Yost (2002) was conducted in Washington State to assess the vibration and noise exposure in forestry workers who engaged in logging road construction, tree felling, bucking and limbing, processing and collecting (yarding and skidding). A recent study by Kim and Chung (2023) evaluated the perspectives of using exoskeletons to increase worker health and safety of chainsaw operators. Bell (2002) has studied the variations in injury rates of loggers in West Virginia with their use of feller-bunchers. Even though these studies are not directly studying the workload, they study the injury rates, the impact of vibrations and noises, pain and MSDs and the perspective of using exoskeletons in forest operations, which are important initiatives in studying forest worker safety.

1.6.3 Studies conducted in other regions of the world

Çalişkan and Çağlar (2010) evaluated the physical workload of chainsaw operators in Turkey forests and identified a heart rate of 122.8 beats per minute while the average resting heart rate was 70.5 beats per minute. The average physical workload (%HRR) measured was 44.79%. According to all the physiological measures, the workload of chainsaw operators was categorized as heavy. Furthermore, Melemez and Tunay (2010) evaluated the physical workload of chainsaw operators by measuring their heart rate. They categorized the chainsaw operators' work as heavy work and assistant employees' work as moderate in terms of physiological workload. The average working heart rate was 115±7 beats/min, and the average resting heart rate was 72-73 beats/min (Melemez and Tunay 2010). A study conducted to assess the physical workload of forestry workers conducting felling, bucking, limbing, choking, timber sorting, manual, semi-mechanical and mechanical loading in Tanzania identified the work as a heavy physical workload after heart rates analysis. The physical strain was measured using the percentage increase in the heart rate while working compared to the heart rate at rest. Tree felling using a chainsaw reported a 68% increase in heart rate compared to resting heart rate. During bucking, it was 65% higher compared to the resting heart rate. They have also observed that the introduction of short breaks during crosscutting operations reduced their average working heart rate to a 48% maximum (Shemwetta et al. 2002). Arman et al. (2021) assessed the physical strain of chainsaw operators working in Northern Iran pine plantations. The highest mean heart rates for different tasks were 117.7 bpm (tree processing), 115.6 bpm (back cut) and 114.8 bpm (undercut), and according to the time study, tree processing was identified as the most demanding task (39.78% of the work time) followed by back cut. Kirk and Sullman (2001) studied the physical workload of cable hauler choker setters in South New Zealand using heart rate indices. They have identified that the choker setter places in the moderate workload category as the relative heart rate was reported as 50% with a mean heart rate of 106 bpm.

Table 1. 2: A summary of studies conducted on the workload of forest logging equipment operators

No.	Citation	Country	Methodology used
European studies			
1	Berger (2003)	Austria	HRV to measure the mental stress of harvester operators Conducted in field
2	Gallis (2006)	Greece	Nordic Standardized Questionnaire to study the prevalence of musculoskeletal symptoms among forest workers Conducted in field
3	Gellerstedt (1997)	Sweden	HRV to measure the workload of forest cleaning machine operators Conducted in the field
4	Grzywinski et al. (2022)	Poland	Heart rate to measure the physical workload of chainsaw operators Conducted in the field
5	Grzywiński and Hołota (2006)	Poland	Japanese questionnaire to measure fatigue of motor-manual and harvester operators Conducted in the field
6	Hagen, Harms-Ringdahl and Myhr (1993)	Norway	Heart rate and oxygen consumption to measure the physical workload of chainsaw operators Conducted in the field
7	Naskrent et al. (2022)	Poland	Eye tracking to measure the mental workload of harvester operators Conducted in the field
8	Spinelli et al. (2020)	Germany	HRV and NASA TLX to measure the mental workload of harvester operators Conducted in lab

9	Szewczyk et al. (2020)	Italy	Eye tracking to measure the mental workload of harvester operators Conducted in the field
North American studies			
10	Bell (2002)	USA	Using worker compensation claims and employment data to calculate logging injury rates associated with feller-bunchers Conducted in the field
11	Kim and Chung (2023)	USA	A sensor study to identify the bio-mechanical stress during the manual timber felling and a survey to assess forest workers' awareness of exoskeletons Conducted in the field
12	Lynch et al. (2014)	USA	Conducted a survey to assess the incidence of self-reported pain and diagnosed MSDs. Conducted in the field
13	Mapatunage (2024)	USA	NASA TLX, heart rate and video recordings to measure the workload of logging equipment operators (wheeled feller-buncher, grapple skidder and knuckle-boom loader) Conducted in the field
14	Neitzel and Yost (2002)	USA	Monitored noise and vibration using datalogging noise dosimeters to measure vibration and noise exposure in forestry workers who engaged in forest operations (felling, logging and log handling) Conducted in the field
15	Smith et al. (1985)	USA	Heart rate and oxygen consumption to measure the physical workload of chainsaw operators (semi-mechanized operations) and feller-buncher, grapple skidder, and knuckle-boom loader operators (mechanized operations) Conducted in the field
Studies from other regions			
16	Arman et al. (2021)	Iran	Heart rate and Swedish Occupational Fatigue Inventory to measure the physical workload of chainsaw operators Conducted in the field
17	Çalişkan and Çağlar (2010)	Turkey	Heart rate to measure the physical workload of chainsaw operators Conducted in the field
18	Melemez and Tunay (2010)	Turkey	Heart rate to measure the physical workload of chainsaw operators Conducted in the field

19	Shemwetta et al. (2002)	Tanzania	Heart rate to measure the physical workload of logging and forest industry employees Conducted in the field
20	Kirk and Sullman (2001)	New Zealand	Heart rate to measure the physical strain of cable hauler choker setters Conducted in the field

1.7 Conclusion

Even though workload studies were started long ago, the topic is still vague. Forest logging is considered one of the most hazardous occupations in the world. Therefore, it is essential to study the workload of forest logging equipment operators to safeguard their occupational health. This literature review aims to explore global workload studies focusing on the research gap, especially in the United States. The majority of the studies on the workload of forestry professionals were conducted in the European region, and there were several studies conducted in other regions, while there were only a few studies conducted in the United States on workload, vibration and noise exposure, and injury rates when conducting forest operations. Forest logging equipment operators always work in a challenging environment in remote sites continuously for a long period of time. Studies have identified that the logging businesses in the southern United States face challenges such as the lack of crew members. Due to this reason, the workload on individual crew members can increase. Physical workload studies were mainly conducted on chainsaw operators. Studies have found that with the mechanization of forest logging, the physical workload has been reduced, and the mental workload has increased, as working with complex machine interfaces involves a lot of decision-making. There is a lack of studies on the mental workload of logging equipment operators in the United States. The NASA TLX is the most commonly used subjective workload assessment technique, as it is easy to use and reliable. The most commonly used objective methods are assessing heart rate, oxygen consumption, HRV and eye movement tracking. Heart rate, oxygen consumption and eye tracking can be conducted using mobile devices, which are less intrusive. Even though brain activity analysis is the most accurate mental workload evaluation method, it cannot be applied to field studies. Due to the challenges the logging industry of the United States is facing, it is important to identify gaps in research to safeguard the occupational health and safety of forestry workers.

CHAPTER TWO

WORKLOAD EVALUATION OF FOREST EQUIPMENT OPERATORS IN THE SOUTHERN UNITED STATES[1]

Abstract

In the Southern United States, logging operations have been mechanized over time, with most loggers using complex and heavy machines for more efficient logging. However, the extensive use of these machineries for long durations increases workload, especially the cognitive demand of the machine operators. Working under demanding conditions can decrease the health of forest equipment operators over time, reducing the productivity of individual operators and increasing the risk of accidents. This study aims to provide an initial assessment of the workload of logging equipment operators during timber harvesting operations using conventional wheeled feller-buncher, grapple skidder, and knuckle-boom loader harvesting systems by assessing the subjective workload of the logging equipment operators. In addition, we observed the heart rate of equipment operators to study the activities causing excessive physical and mental workload. Logging equipment operators self-evaluated their workload using the NASA Task Load Index, a subjective measure of workload. Results show no significant difference in the overall workload of equipment operators working at clearcut and thinning sites. The workload dimensions of Effort and Frustration contributed the most to the overall workload, while Performance had the least

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[1] The content in this chapter was included in a manuscript submitted to the Journal of Forest Engineering which will be changed according to the revisions (Mapatunage et al. 2024).

contribution. Sudden heart rate spikes occurred when operators conducted physical activities such as clearing debris from a felling head but were otherwise unobserved.

2.1 Introduction

The forests in the southern United States are referred to as the wood basket of the country, with a 71% planted timberland rate, the highest timberland rate in the nation and the southeastern logging operations are considered one of the most productive logging businesses in the entire country as their annual production rates were seven times greater than the other regions of the U.S. (Conrad 2018; Oswalt et al. 2019). Logging operations have been mechanized over time in the United States, decreasing the logging injury rate (Milburn 1998). There are complex and expensive machineries used for felling, delimbing, skidding and loading (Melemez and Tunay 2010). As people have to work with complex interfaces and are often required to work for long periods under demanding conditions, workers have to stay focused to avoid accidents, which causes a high mental workload even though there is a reduction in physical workload (Heinimann 2007; Spinelli et al. 2020; Bafna and Hansen 2021).

Workload is a hypothetical construct representing the effort a human operator uses to achieve a certain performance level (Hart and Staveland 1988). Physical workload occurs because of muscle functions. Musculoskeletal health problems arise when the physical stress on the body exceeds the ability of the locomotor system's parts to handle it (López-Aragón et al. 2017). Physical workload occurs when workers carry or handle heavy loads in the wrong postures or engage in repetitive activities (López-Aragón et al. 2017).

Heart rate and oxygen consumption are the two most common methods to measure the physical workload (Grandjean 1980; Shemwetta et al. 2002; Melemez and Tunay 2010). The heart rate increases with the intensity of work, and there is a close relationship between heart rate and the oxygen demand of the human body (Andersen et al. 1978).

Most physical activities done by workers were gradually replaced with machines that reduce the physical workload on humans (Miller 2019). However, shifting from physically tiresome motor-manual forest logging to fully mechanized logging has caused an increase in the mental demand of harvesting equipment operators (Heinimann 2007). Mental workload includes a range of procedures incorporating neurophysiological, perceptual, and cognitive functions (Baldwin and Coyne 2003). It refers to the amount of information processing capability assigned to accomplishing a task (Pereira 2014). Every task humans engage in requires mental effort to some extent, contributing to varying levels of mental workload (Mitchell 2000). The idea of mental workload emerged considering various crucial factors involved in executing a task, such as the properties of the task, the environment in which the task is performed, and the subjectivity of the human operator to the mental workload (Longo 2016).

The increased mental workload of working with multi-functional heavy forestry equipment can cause fatigue in the central nervous system (Szewczyk et al. 2020). In a stressful situation, the autonomic nervous system suppresses the parasympathetic nervous system and activates the sympathetic nervous system, and this causes the release of the stress hormones adrenaline and noradrenaline (Akselrod et al. 1981; Taelman et al. 2008). The hypothalamus will initiate the production of these hormones through the sympathetic nervous system by activating the adrenal cortex (Berger 2003). As these hormones transport glucose and fat to the body muscles, the oxygen demand and heart rate will increase, raising the blood pressure and reducing heart rate variability, which are the physiological measures of workload (Berger 2003).

Research on workload has been conducted since the integration of humans with machines, and researchers have identified methods to measure the workload accurately and determine what level of workload is excessive for the workers (Miller 2019). Workload studies have been conducted worldwide, and the concept of workload was initially developed for use in aviation contexts (Hart 2006; Gore 2017). Later, workload studies were conducted in other fields, such as medical, manufacturing industries, and construction, to determine the excessive workload for workers and provide solutions to minimize it (Gore 2017; Bafna and Hansen 2021).

There are different methods used to evaluate workload, but most fall into two categories: subjective and objective methods. In subjective methods, workers are asked to self-report their workload using a questionnaire/survey. For example, the most common methods are the NASA Task Load Index (NASA TLX) (Hart and Staveland 1988), the Chalder Fatigue Scale (Chalder et al. 1993) and the Nordic Standardized Questionnaire (López-Aragón et al. 2017). For the objective methods, physiological measurements such as heart rate and heart rate variability (Taelman et al. 2008), eye movement tracking (Yamanaka and Kawakami 2009), and analysis of brain function (Aghajani et al. 2017) are used.

The majority of workload studies in forestry have been conducted in Europe. The physical workload of forest equipment operators, including both harvester and motor-manual operators, was studied in Turkey (Çalişkan and Çağlar 2010; Melemez and Tunay 2010), Greece (Gallis 2006), and Sweden (Rehn et al. 2009). The mental workload of harvester operators was studied in Sweden (Gellerstedt 2002), Poland (Naskrent et al. 2022), and Italy (Spinelli et al. 2020; Szewczyk et al. 2020). However, studies conducted on the workload of logging equipment operators in the United States are limited. Smith et al. (1985) evaluated the heart rate response for forest harvesting work during summer in the southeastern United States. Lynch et al. (2014) conducted a study about the impacts of extended working hours in the logging industry in the southeastern United States, assessing the musculoskeletal disorders and neck and back pain among logging equipment operators. The study by Neitzel and Yost (2002) was conducted in Washington state to assess the vibration and noise exposure in forestry workers. A recent study by Kim and Chung (2023) evaluated the perspectives of forestry professionals on using exoskeletons to increase worker health and safety. A human exoskeleton is a wearable structure that has been developed to provide support to the postural structure of the human body and to enhance the physical capabilities of workers (Schnieders and Stone 2017). According to a literature review (Mapatunage 2024), no studies have been conducted on the mental workload of logging equipment operators in the southern United States.

This study aims to provide an initial assessment of the workload of logging equipment operators during timber harvesting operations while operating conventional wheeled feller-buncher, grapple skidder, and knuckle-boom loader harvesting systems in the southern U.S. The objectives of this study are to assess and document the subjective workload of logging equipment operators using South Carolina loggers as a proxy for southern US loggers and to use heart rate changes to evaluate the workload associated with observed activities.

2.2 Methodology

2.2.1 Study Site

This study was conducted in South Carolina. The total land area of South Carolina is approximately 8.3 million hectares, including 5.2 million hectares of forestland (USDA Forest Service 2021). Of this forestland, about 86% is privately owned, while approximately 8% is federally owned, and around 5% is owned by state and local governments. South Carolina contains a diverse mix of hardwood (52%) and softwood (48%) dominated forests grown across different landscapes, starting from the coastal plains to the mountain region of Appalachia (Craig and Monroe 2020; South Carolina Forestry Commission 2021). According to the USDA Forest Service inventory, there are approximately 9 billion live trees in the state with a volume of 776 million cubic meters (USDA Forest Service 2021). About 190,000 hectares of forest land are harvested annually (USDA Forest Service 2021) using mostly a conventional harvesting system consisting of a wheeled feller-buncher, grapple skidder, and knuckle-boom loader with pull-through delimber (Conrad et al. 2018). The annual economic impact of forestry in South Carolina is approximately $23.2 billion (von Nessen 2022).

2.2.2 Subjective Workload Study

The study was conducted at seven logging sites, two clearcuts and five thinning operations. We collected 19 responses from logging equipment operators, including six feller-buncher operators, six loader operators and seven skidder operators, about their subjective workload using the NASA TLX (Hart and Staveland 1988; Hart 2006). The NASA TLX is a multi-dimensional method of ranking that gives an overall score for the workload based on a weighted average of ratings on the six most relevant dimensions identified to affect workload: Mental Demand, Physical Demand, Temporal Demand, Effort, Performance and Frustration (Figure A.1). The pairwise comparison of six dimensions provides the weight, which is the degree to which each dimension contributes to the workload out of the six, according to the rater's viewpoint (Figure A.2). Each of the above dimensions was given a scale from low to high (0 to 100 for data analysis) and was associated with the definitions provided by the NASA Human Performance Research Group (NASA Ames Research Center 1986; Table 2.1). The overall workload for each worker is calculated by multiplying each dimension rating by the weight given to that dimension. Then, the sum of these weighted ratings given to all six dimensions is divided by 15, which is the sum of all the weights (NASA Ames Research Center 1986).

We asked each operator to rank the importance of each of the six dimensions toward their workload using a pairwise comparison (Hart and Staveland, 1988). We also asked each operator to focus on the current harvest site and the task they were assigned when answering the NASA TLX questions. We used the "NASA TLX" app to collect all data on an iPad. In addition, we collected demographic information of operators, such as gender, age, height, weight, logging experience, experience with machine type, and a yes/no question about any health conditions that may impact the heart rate. We also collected information about the harvest (thinning/clearcut) (Figure A.3).

Table 2. 1: Definitions of the six dimensions of the NASA Task Load Index provided by the NASA TLX manual (NASA Ames Research Center 1986)

Dimension	**Definition**
Mental Workload	How much cognitive and perceptual activity was necessary (e.g., Thinking, deciding, calculating, remembering, looking, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
Physical Workload	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal Workload	How much time pressure did you feel due to the rate or pace at which the task or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Performance	How successful do you think you were in accomplishing the goals of the task? How satisfied were you with your performance in accomplishing these goals?
Effort	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

2.2.3 Heart Rate and Video Study

To assess specific physical and mental workload activities, we collected heart rate and video data for all logging equipment operators. To collect heart rate data, operators wore the Polar Verity Sense Model 4J heart rate monitor armband on their forearms below the elbow while working. A heart rate monitor is minimally invasive to the work conducted by the operator (Henriksen et al. 2018). We also mounted a GoPro Hero camera using a suction cup on the windshield of the machine to simultaneously record the work these equipment operators do for about 90 to 120 minutes. We uploaded the heart rate data to the Polar Flow app and exported the heart rates of workers recorded every second to an Excel sheet. We qualitatively analyzed the heart rate data simultaneously with the video recordings of each operator to see if any drops or spikes in heart rate were linked with specific activities. We removed the first and last 3 minutes of the videos to remove the error of sudden heart rate variation at the start and finish of work due to the physical activity of getting into or out of the equipment. As we were not able to collect a resting heart rate at night from equipment operators, we defined a drop or spike in heart rate as any heart rate that was above or below one standard deviation around the average observed heart rate.

2.2.4 Data Analysis

We first calculated the descriptive statistics, which were the average overall workload, average workload ratings for each dimension, and the body mass index (BMI). To calculate BMI, we used the height and weight of the equipment operators (BMI = weight (lbs) / [height (in)]2 x 703). We used Welch's t-test to compare the workload ratings between clearcut and thinning sites. We also conducted a one-way ANOVA to compare the workload ratings between the six dimensions of the NASA Task Load Index. We used the Tukey-Kramer HSD post hoc test to identify which dimension ratings and weights were significantly different compared to other dimensions. We used ANCOVA (analysis of covariance) to compare the overall workload ratings between clearcut and thinning sites, considering the effects of BMI and the age of the operators.

Before conducting the analysis, we checked for the normal distribution of our data and evaluated the assumptions of independence and homogeneity of variance. We analyzed data using JMP software, R, and Microsoft Excel.

2.3 Results

2.3.1 NASA TLX Study

All equipment operators were male, and their ages ranged from 21 to 72 years. The BMI of the equipment operators ranged from 23.6 to 38.1. Only 2 operators were in the healthy BMI range (18.5 kg/m^2 to 24.9 kg/m^2), 5 operators were in the overweight (25 kg/m^2 to 29.9 kg/m^2) range, and 12 were in the obese (30 kg/m^2 or greater) range (Atlantis et al. 2010). Their experience working in their type of equipment ranged from 3 months to 45 years. The slope of the work sites ranged from 0% to 8%. At the observed sites, they mostly harvested loblolly pine (*Pinus taeda* L.) trees, with one harvest site consisting of a natural mixed-wood stand.

When comparing the workload for each equipment operator type separately, the average workload was highest for the feller-buncher, followed by the skidder and loader operators (Table 2.2). For all the equipment operator types, the workload dimension of Effort was listed as adding the most to the overall workload (Table 2.2). Due to the small number of samples for each operator type, we combined all equipment operators for subsequent data analysis.

Table 2. 2: Average workload and ratings for logging equipment operators. The workload ratings provided by the NASA TLX are unitless and provide a reference point for relative comparisons only.

Equipment Operator	n	Overall workload	Mental demand	Physical demand	Temporal demand	Performance	Effort	Frustration
Feller-buncher	6	64.2±12.9	61.7±10.3	65.0±13.8	73.3±17.2	15.8±9.3	75.0±14.4	57.5±24.3
Grapple Skidder	7	55.5±8.8	55.7±11.4	50.7±10.5	64.3±18.2	15.7±6.2	74.3±15.2	62.1±12.8
Knuckle-boom Loader	6	46.7±17.8	45.0±21.0	34.7±20.3	55.0±25.8	10.8±6.7	78.3±20.3	61.7±28.1

When comparing the workload of equipment operators between clearcut and thinning sites, without considering the equipment type, the highest workload ratings were given to Effort and Frustration workload dimensions by all the operators at both clearcut and thinning sites and the lowest rating was given to the Performance workload dimension (Figure 2.1). The average overall workload at clearcut and thinning sites, respectively, were 64.47 and 52.24, with no significant difference (p=0.085) between them (Figure 2.1). For each of the six workload dimensions, there was no significant difference (p>0.05) between the workloads for clearcut (n=5) and thinning (n=14) sites (Figure 2.1). There was also no significant difference between the overall workload at clearcut and thinning sites when considering the effects of BMI and the age of the operators (p=0.148) and BMI (p=0.138).

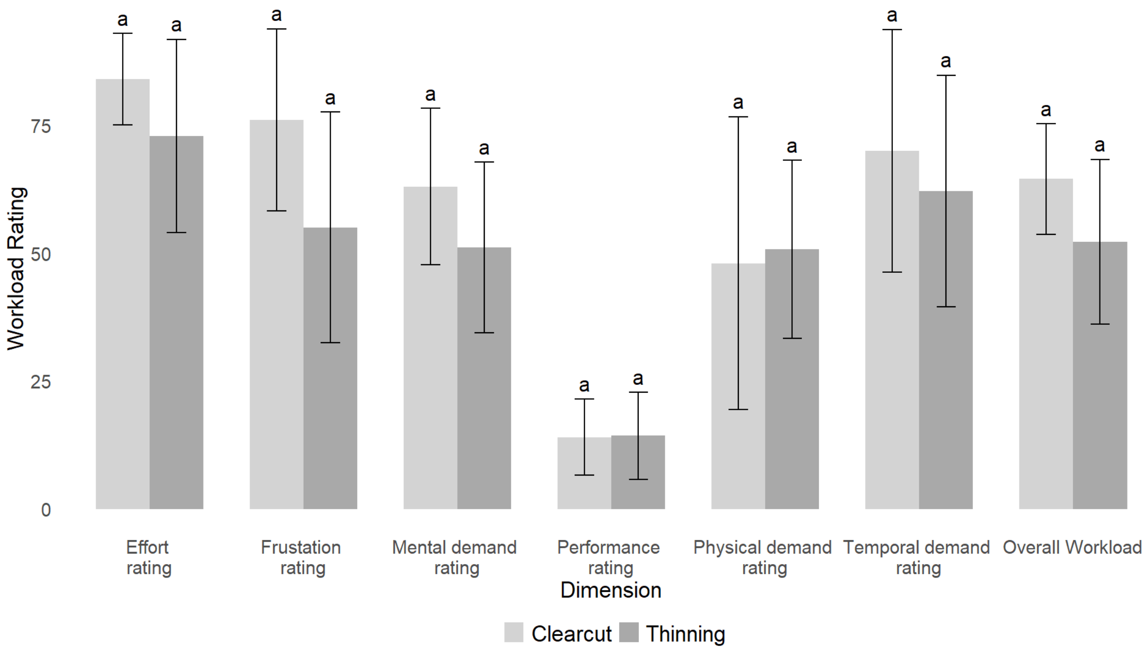


Figure 2. 1: Average overall workload and workload dimension ratings (Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, Frustration) for logging equipment operators for clearcut (n=5) and thinning (n=14). The letters above the bars show the statistical difference between clearcut and thinning operators' mean workload ratings for each dimension.

As there was no difference in workload between thinning and clearcut sites, we combined all workload responses to see if any single workload dimension adds significantly more to the overall workload of an operator. Performance has a significantly lower impact on workload than any other dimension ($p<0.001$). The low average of the Performance dimension indicates that most operators are satisfied with their performance and how well they have achieved their goals at the harvest site. The Effort, Frustration and Temporal Demand workload dimensions, however, contributed the most to the overall workload of the equipment operators (Figure 2.2).

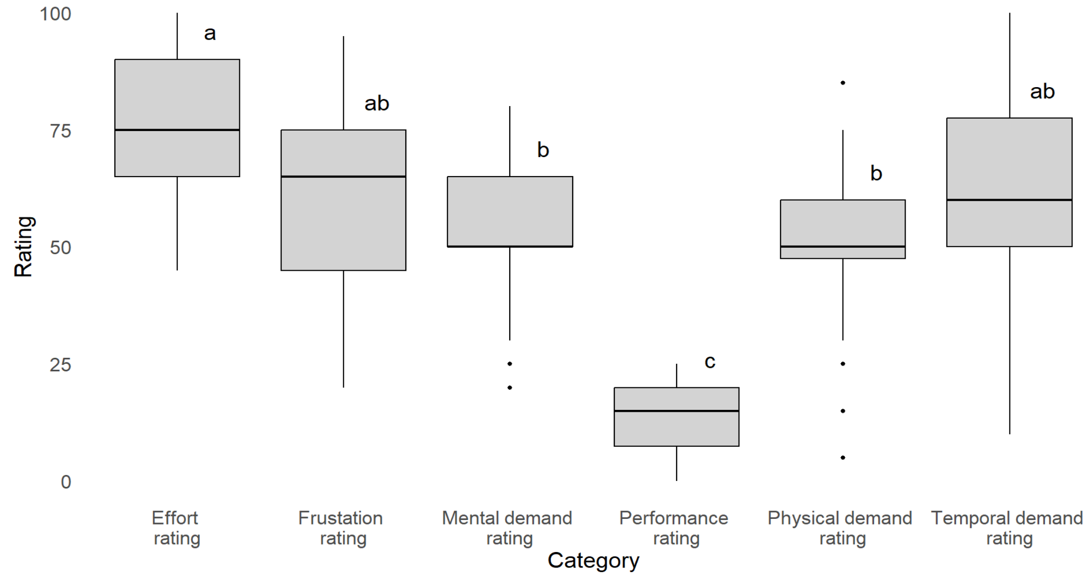


Figure 2. 2: Boxplot of the workload ratings by workload dimensions for all the operators (n=19). The letters above the box show statistical differences between dimensions.

2.3.2 Heart Rate and Video Study

During typical feller-buncher activities, we did not find many spikes in heart rates. But when we did observe spikes, those were due to physical activities. For instance, one feller-buncher operator stopped working for a few minutes and got out of the cabin to clean the saw blade at point 2 (Figure 2.3a). The sudden low heart rate recorded at point 3 was when he stopped working for a few seconds and the small heart rate spike at point 4 was due to the moving of the vehicle on a slope. Another feller-buncher operator had a sudden heart rate spike (point 6) when moving the feller-buncher up on a slope while doing a 1st thinning in a stand with small hardwoods and shrubs (Figure 2.3b). Another feller-buncher operator was working in a natural mixed wood stand, cutting hardwood trees while clearing the area by cutting saplings (Figure 2.3c). There were several high and low heart rate spikes recorded for this operator. Some low heart rates were observed at point 8 when cutting saplings to clear the area. Low heart rates were again observed at points 10 and 11. This was when the operator cut two large trees. He partially cut the large tree and stopped for a moment, then did a second cut to fall the tree. The causes of other heart rate spikes, including the variations at point 9, are unknown. The heart rate spikes at the beginning of Figures 2.3a-c (points 1, 5 and 7) are remnants of increased heart rate after climbing into the operator cab, beyond the 3 minutes of data collection that was already excluded.

Skidder operators were always working inside the cabin and did not perform any significant physical activities. There were some variations in heart rates for the below skidder operators, but there were no individual high heart rate spikes. The heart rate of the skidder operator (Figure 2.4a) was either consistently above or below one SD around the average heart rate but got lower over time. The two heart rate spikes at points 2, 3 and 4 were when the skidder operator was bringing the trees to the landing and delimb branches using the delimbing gate (Figure 2.4a). For another skidder operator in Figure 2.4b, the heart rates showed some variations within the one SD range and sudden drops in his heart rate were observed when he stopped working for a few minutes at points 6, 7, 8 and 9 (Figure 2.4b). The causes of other sudden variations of the skidder operator's heart rate are unknown. The high heart rate spikes at the beginning of Figure 2.4a and 2.4b (Points 1 and 5, respectively) are remnants of increased heart rate after climbing into the operator cab, beyond the 3 minutes of data collection that was already excluded.

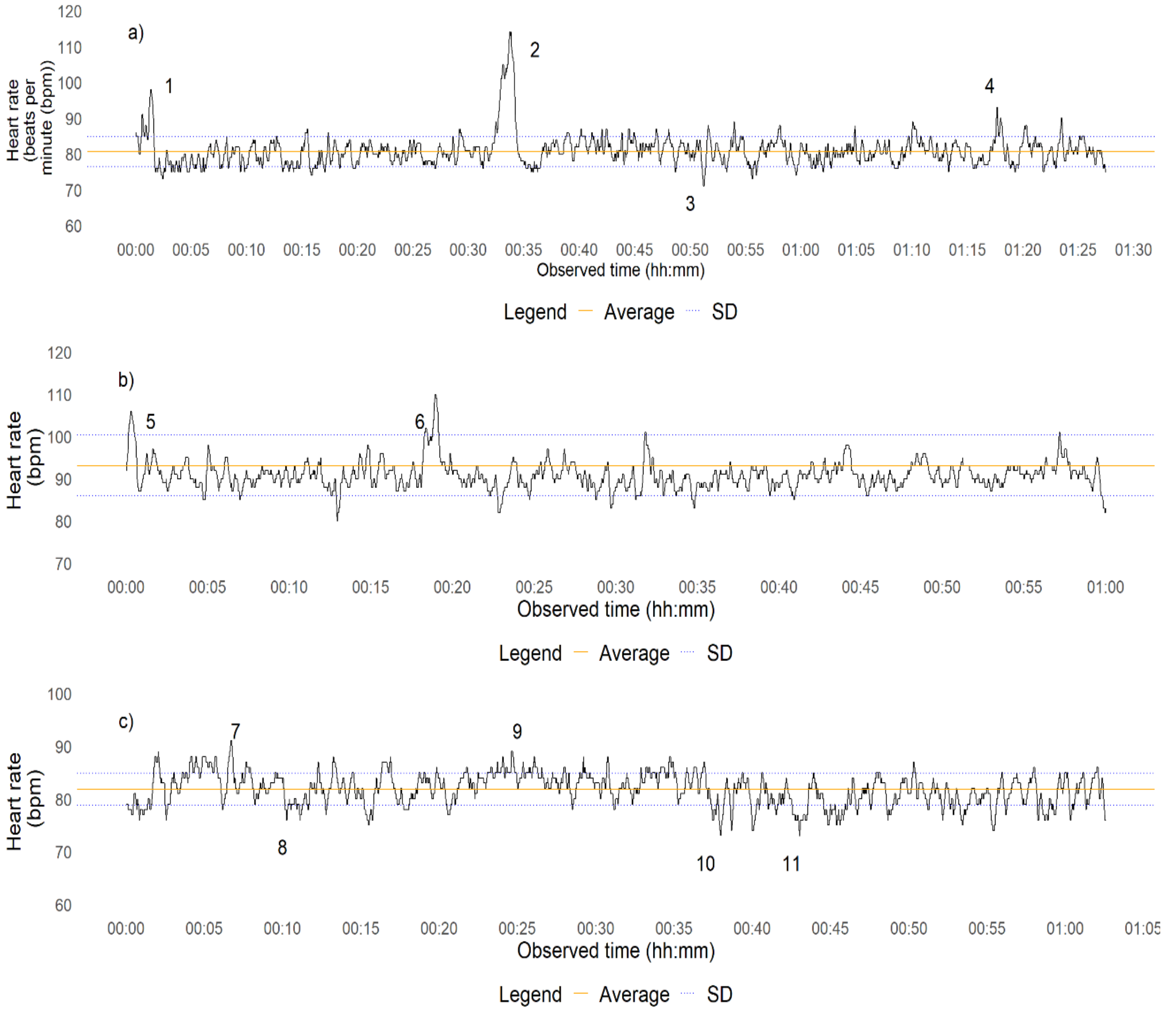


Figure 2. 3: Heart rate variations of three feller-buncher operators. The heart rate spike (2) of the feller-buncher operator was when he cleaned the debris from the saw blade. The low heart rate at point 3 was when he stopped working for a few seconds and the spike (4) was at the time when he moved the equipment on a slope (Figure 2.3a). Heart rate spike (6) was when the operator moved the equipment on a slope (Figure 2.3b). The high heart rate spikes at the beginning of Figure 2.3a-c (Points 1, 5 and 7) were at the start of the work while climbing to the equipment and starting the machine. The low heart rate at point 8 was when he was clearing the forest by cutting down young trees (poles), and at points 10 and 11 when the operator stopped working for a few seconds after doing an undercut (Figure 2.3c).

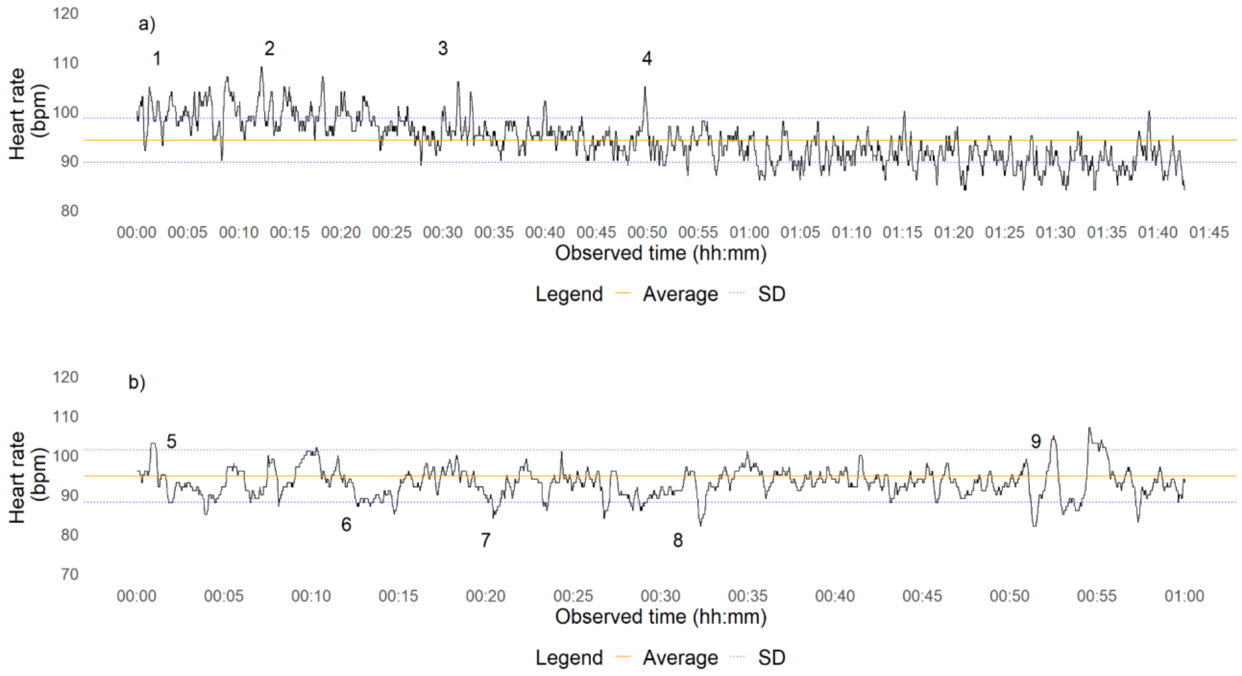


Figure 2. 4: Heart rate variations of two skidder operators. The spikes at points 2,3 and 4 of the operator (Figure 2.4a) were when he was bringing trees to the landing and using the gate delimber. The low heart rates at points 6, 7, 8 and 9 of the skidder operator (Figure 2.4b) were when the operator stopped working for a few minutes and resumed back to work. The heart rate spikes at the beginning (points 1 and 5 of Figure 2.4a and 2.4b, respectively) were at the start of the work while climbing to the equipment and starting the machine.

Several loader operators had variations in heart rates while conducting different activities. The high heart rates (points 1 and 2) of the loader operator (Figure 2.5a) occurred when he had to trim the branches from trees loaded onto two log trucks using a chainsaw. After that, there was a pattern of a few minutes of higher heart rates (points 3 and 4) when he was processing the bunch of trees brought by the skidder operator and a few minutes of lower heart rates (points 5 and 6) when he was resting until the skidder operator brought the next bunch of trees to the landing (Figure 2.5a). Another loader operator had a high heart rate increase (point 7) when loading logs onto two log trucks consecutively (Figure 2.5b). The heart rate spikes at the beginning (point 8) are due to processing a pile of large hardwood and softwood trees (Figure 2.5c). Then, the operator stopped working until he received another load of trees to process at point 9. The cause for the heart rate spike at point 10 is uncertain.

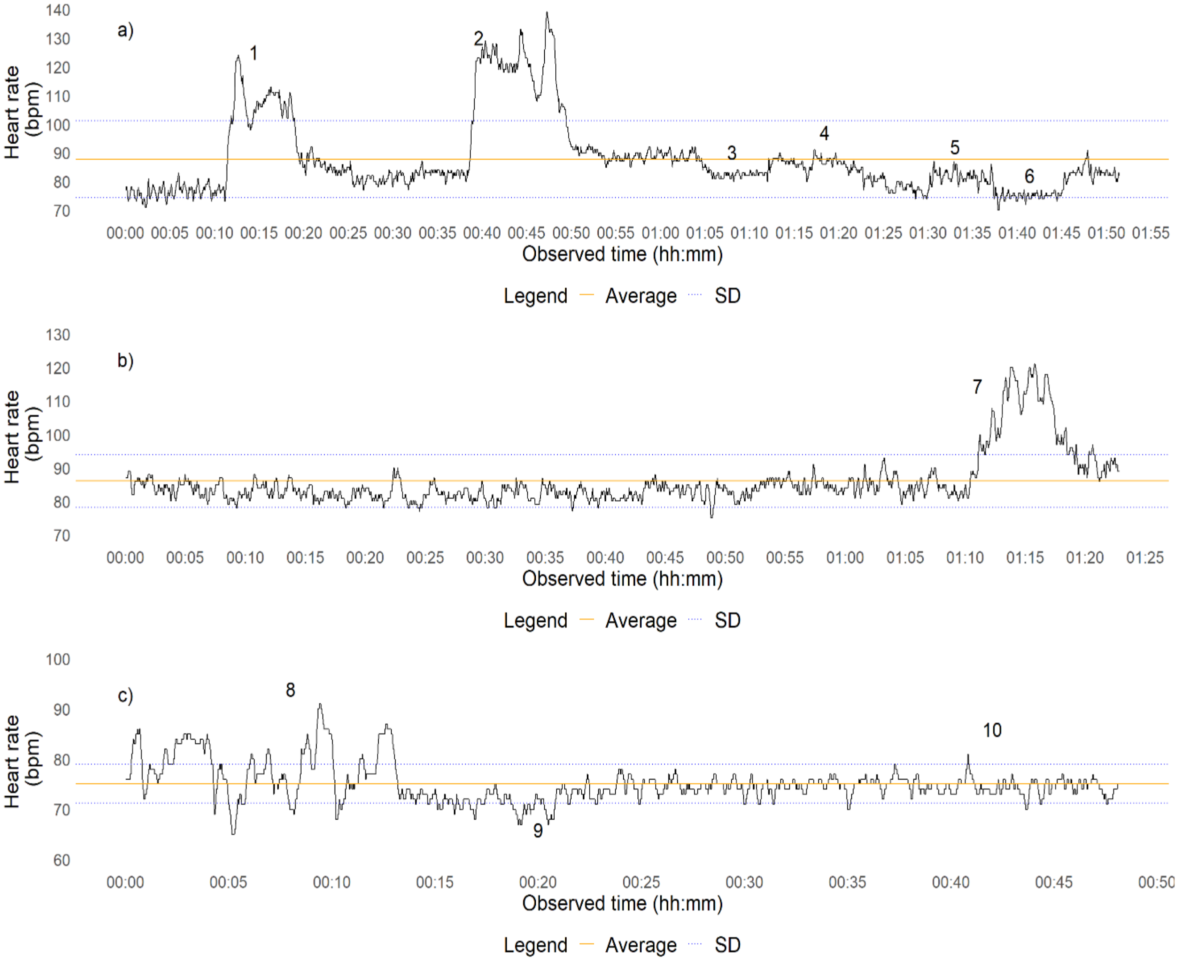


Figure 2. 5: Heart rate variations of three loader operators. The two heart rate spikes at points 1 and 2 of the loader operator (Figure 2.5a) were when he was trimming branches from the

trees loaded to the log truck. The higher heart rates at points 3 and 4 were when the operator was processing timber, and lower heart rates shown by points 5 and 6 were when the operator was resting until the next bunch of trees were brought to the landing. The high heart rate spikes of the loader operator (Figure 2.5b) at point 7 were when he was loading logs onto two log trucks consecutively. The heart rate spikes at the beginning (point 8) of Figure 2.5c were due to the effect of starting to work and processing a large pile of hardwood and softwood trees. Point 9 was when the operator waited for another load of trees to process. The cause for the heart rate spike at point 10 was uncertain.

2.4 Discussion

Forest logging is considered one of the most hazardous occupations in the world (Holman et al. 1987; Slappendel et al. 1993). Moreover, according to the United States Bureau of Labor Statistics, forest logging is one of the most hazardous occupations in the United States, with over 80 fatalities per 100,000 workers in 2020 and 2021 (Bureau of Labor Statistics 2022). There are several factors affecting the workload at a forest logging site that can cause hazards: personal characteristics of the workers, machinery, tools and equipment used, work organization, and the physical environment (Slappendel et al. 1993). There is a popular statement that forestry is a 3D job, which means it is dangerous, dirty and difficult, and this statement is proven by the facts that the work is done outdoors, and the operators have to work sometimes under extreme weather conditions such as cold, snow, rain and ultraviolet radiation (Shemwetta et al. 2002).

2.4.1 NASA Task Load Study

In this study, the overall workload of the equipment operators working at clearcut sites and thinning sites was not significantly different. However, Naskrent et al. (2022) have found a high mental workload for harvester operators at clearcut sites during both day and night compared to thinning operations. This could be because those operators were working in harvesters and in wind-damaged sites. At one clearcut site we collected data from a natural mixed wood stand in which we observed the feller-buncher and loader operators felling and processing pine and hardwood trees separately. This can add to the workload of operators. Spinelli et al. (2020) showed increased mental demand, effort and frustration of harvester operators when they shifted from pure conifer stands to mixed wood stands.

The NASA-TLX demonstrated effectiveness in identifying discrepancies between tasks and the primary factors contributing to increased workload (Spinelli et al. 2020). The ratings are the operator's felt magnitude of each dimension (NASA Ames Research Center 1986). For the workload ratings for all the equipment operators combined, the mean rating for Effort was high, with Frustration having the second highest rating. Despite several skidder operators expressing frustration during data collection, particularly at thinning sites where they had to navigate back and forth along the trail while turning their necks to reverse the skidder and avoid trees, the overall workload findings from the small sample size do not indicate a significant difference in overall workload between clearcut and thinning operations. A few loader operators also stated that they are working under pressure as they are not only processing logs but also have to load as many log trucks as they can to get paid for logs they processed on that day. The lowest rating was given to the Performance workload dimension, which indicates that operators were generally very successful in accomplishing the task they were asked to do.

2.4.2 Heart Rate Study

The heart rates of equipment operators showed an evident variation when they were doing physical activities. These could vary according to the job performed by the equipment operator at the logging site (Slappendel et al. 1993). For the feller buncher operators, cleaning debris from the saw blade caused heart rate spikes. Smith et al. (1985) also indicated that the manual and semi-mechanized tasks are potentially more stressful compared to the fully mechanized tasks. Moving the equipment on slopes also caused heart rate spikes. This could be due to the increase in workload as the operator has to control heavy equipment on a slope and has to concentrate more on the task. (Szewczyk et al. 2020) also stated that with the increment of slope gradient the mental workload of harvester operators increased. Sudden drops in heart rates below their average working heart rates were observed when the equipment operator stopped working for a few minutes.

There weren't specific individual heart rate spikes for the skidder operators, and they didn't perform any physical activities. This could be because skidders were usually assigned to new operators with less experience in logging, and their jobs had fewer responsibilities, while feller-buncher and loader operator jobs are considered as jobs with higher responsibilities (Lynch et al. 2014). For some loader operators, the variations of the heart rates increased significantly while loading logs onto the log trucks. Also, heart rate data showed a significant workload pattern for a loader operator for his working heart rate (delimbing and sorting logs) and resting heart rate (when he was not working and was for the next bunch of logs the skidder brought to the landing). This could be because, compared to resting time, the timber processing task is more physically demanding. We observed that the operator had to use their hands to control the machine while focusing on the number of elements in front of his visual scene, including the logs, loader head, machine parts, and sorting timber into piles of different sizes. This fact was also observed by Naskrent et al. (2022) for harvesters. Even though sudden changes in physical activities or an increase in the complexity of work caused a rise in heart rate, there were no continuing high heart rates throughout the observed time period for the logging equipment operators. Naskrent et al. (2022) also found that the harvester operator's energy expenditure fluctuates between 3.1 and 5.6 kJ/min, and based on the categorization of physical effort intensity, this falls within the classification of light work. However, loader operators interviewed for the study stated that they are working under pressure as they are not only processing logs but also have to load as many log trucks as they can to get paid for the logs they processed.

2.4.3 Limitations of the Study

It is important to state the limitations of this study to ensure that any conclusions drawn are approached with the necessary care and caution. In NASA TLX studies, the responses are subjective. Therefore, the answers can be biased according to their individual experiences and emotions. The study participants can have a pre-defined concept about the workload, which makes their ratings biased. It is implausible for them to know the variables of their tasks and the process that causes their actions (Hart and Staveland 1988). One of the major limitations of using self-evaluating methods is that it limits the depth researchers can dive into the research problem (Szewczyk et al. 2020). Respondents always have different types and levels of emotions, and the effect of these emotions when filling out the questionnaire is hard to prevent (Spinelli et al. 2020; Szewczyk et al. 2020). To mitigate the effect of emotional involvement during the self-reporting of NASA TLX, we asked them to fill out the questionnaire at the work site itself. We also advised them to recall the work they had been doing at that particular work site. Therefore, it is best to use subjective methods with objective measurements to check if the results of the two methods reciprocate (Szewczyk et al. 2020). It would have been beneficial to involve more participants in the research, but the study faced significant constraints due to a shortage of available subjects during the time period of our study.

2.5 Conclusion

The result of this study represents the relationship between physical and mental workload within the logging industry, emphasizing the shift from manual labor to mechanization. While technological advancements have alleviated some physical strain, they have introduced new complexities, amplifying cognitive demands for equipment operators. Highlighting the nature of workload for loggers, this study identifies Effort and Frustration as the primary contributors to overall workload, while performance plays a lesser role. Additionally, insights into elevated heart rates during specific activities, such as loading logs onto trucks, emphasize pivotal areas for intervention and potential workload mitigation strategies. The findings highlight a need for holistic workload evaluations, encompassing both physical exertion and mental strain. Notably, this study reveals the need for advanced research specifically examining the mental workload of loggers in the United States, urging a call for comprehensive investigations into this issue of their occupational health. Moreover, it is essential to conduct advanced studies focused on the equipment types that can cause high workloads and workloads at different site conditions. Urgent attention is necessary to address these research gaps, ensuring the integration of workload considerations into future decision-making processes to safeguard the well-being and sustainability of the forestry industry.

CHAPTER THREE

ASSESSING THE WORKLOAD OF PRESCRIBED FIRE AND WILDFIRE PROFESSIONALS

Abstract

Fire is a frequent type of disturbance that occurs in forests. Due to human influence, the natural fire cycles have changed, and severe wildfires have occurred due to heavy fuel collected on the forest floor. Prescribed fires were introduced to reduce hazardous fuel loads and meet ecological restoration objectives. Those who control and fight these fires include private contractors, state/federal agency personnel, and landowners. These fire workers must work under demanding conditions for long hours while controlling and fighting fires. Little is known about the workload of these fire workers, and this study aims to evaluate the subjective workload of forest fire workers in the southern United States. The NASA Task Load Index was completed by forest fire workers in North and South Carolina, focusing on their workload at the most recent prescribed fire and/or wildfire they worked on. There were 21 respondents, of which all had experience working in prescribed fires; however, only 15 respondents had experience working with wildfires. The people who responded to the survey were between 23 and 64 years old. The average prescribed fire size they worked on was 72 acres, while the average wildfire size was 1,235 acres. The results showed no statistically significant difference in the self-reported workload of the fire workers working in prescribed fires and wildfires. When all workload data were combined, the workload dimensions of Effort, Physical Demand, and Mental Demand contributed the most to the overall workload, while Performance contributed the least.

3.1 Introduction

Fire is a natural component in forests and is a frequent type of disturbance that occurs in forests all over the world. Accumulated fuel on the forest floor can lead to severe wildfires (Nowacki and Abrams 2008; Ryan et al. 2013). The 1994 and 2000 active fires showcased the effects of fire suppression bringing up the attention of fire policy towards reducing fuel and recognizing fire as an important ecological process (Williamson 2007). These fires play a crucial role in hazard reduction, silviculture practices (site preparation and managing competing vegetation), wildlife habitat enhancement, conservation of ecosystems, and insect and disease control (Weber and Taylor 1992). In the southeastern United States, prescribed fires are particularly prevalent due to the diverse species available in the region, many of which are fire-adapted (Nowacki and Abrams 2008). For instance, longleaf pine in this region has evolved, with historical fires occurring every few years (Frost 1993; Jose et al. 2006).

Both prescribed fires and wildfires play a vital role in the ecosystems of the Southern United States (Korhonen 2023; National Interagency Coordination Center 2023), and plant species grown in these forests adapted to fire over time (Brenda et al. 2021; Weise 2023). Prescribed fires are mainly used in the southeastern United States to remove the fuel on the forest floor to reduce the risk of wildfires or to maintain the fire-adapted forest structure (Elliott and Vose 2005). Four southern states were among the top five states with the highest annual average prescribed burning areas in 2017, including Florida (2,182,980 acres), Georgia (1,255,221 acres), Alabama (944,455 acres), and South Carolina (342,066 acres) while North Carolina (180,558 acres) is placed at the ninth place (Korhonen 2023). According to the

National Interagency Coordination Center Wildland Fire Summary for 2023, 25% of the nation’s total wildfire-burned land area occurred in the Southern United States (National Interagency Coordination Center 2023). Wildland firefighting is a physically demanding occupation (Gumieniak 2017). Wildland firefighters around the world face an increased demand due to the risk of longer and more frequent fires (Phillips et al. 2012). Federal land management agencies, such as the United States Forest Service, Bureau of Land Management, and National Park Service, mainly supply wildland firefighters (Ryan et al. 2013; Jahn and Black 2017). Wildland fire units consist of different wildland fire functionalities (Jahn and Black 2017), such as command and general staff, fire management, duty officers and incident command team members. The direct engagement and implementation positions include on-the-ground firefighters and non-engagement support personnel (Jahn and Black 2017). Wildland firefighters conduct a variety of tasks to control fires, including operating fire engines, constructing firelines, mop-up and fire operations (Navarro 2020).

Studying the workload of forest fire fighting is important not only for the conservation of natural resources but also due to the dangerous work environment for firefighters (Apud and Meyer 2011). Wildland firefighters have to work under demanding conditions for long hours while controlling fires (Navarro 2020). Several factors contribute to the workload of firefighters, such as the condition of the site, fuel types burning, the organization of work, the number of members in a crew, the position of the worker in a fireline, job rotation and allocation of breaks and the climatic condition of the site (Apud and Meyer 2011).

The literature on the workload of forest firefighters is limited. Phillips et al. (2012) have tried to identify which tasks are physically demanding during bushfire suppression by Australian rural firefighters. A study conducted in Chile explores the environmental factors affecting the workload of forest firefighters (Apud and Meyer 2011). To understand the work pressure of wildland fire fighting in New Zealand, an observational study was conducted by letting two firefighters wear microphones, miniature video cameras, heart rate monitors and GPS units to record their actions (Parker et al. 2017). Other literature concerning wildfire suppression was mainly focused on the physical and occupational risks, such as inhalation of smoke (Liu et al. 1992). With the limited literature on forest fire workers' workload in the United States, this study aims to provide an initial assessment of the workload of forest fire workers in the southern United States. The objectives of this study are to assess and document the subjective workload of forest fire workers in North and South Carolina working in prescribed fires and wildfires.

3.2 Methodology

3.2.1 Qualtrics Survey

An online survey was developed using the Qualtrics platform (Table A.1). The survey consisted of three parts: (1) questions related to experience working prescribed fires, (2) questions related to working wildfires, and (3) demographic questions (Figure 1). The survey collected responses from the forest fire workers about their subjective workload using the NASA Task Load Index (NASA TLX) (Hart and Staveland 1988; Hart 2006). The survey included multiple decision-making questions that will lead them to answer the questions about prescribed fire and wildfire experiences, as shown in Figure 3.1. The NASA TLX is a method of ranking that gives an overall score for the workload based on a weighted average of ratings on the six most relevant dimensions identified to affect workload: Mental Demand, Physical Demand, Temporal Demand, Effort, Performance and Frustration (Table 3.1). Each of the above dimensions was given a scale from low to high (0 to 100 for data analysis) and was associated with the definitions provided by the NASA Human Performance Research Group (NASA Ames Research Center 1986). We asked each fire worker to rank the importance of each of the six dimensions toward their workload using a pairwise comparison as required by the NASA TLX (Hart and Staveland 1988). At the end of the survey, we also asked each participant for demographic information such as the year of birth and gender. As an incentive to participate in the survey, each participant had the option to provide a mailing address to receive a Buck Bantam folding knife.

Table 3. 1: Definitions for the six NASA Task Load Index dimensions provided by the NASA Human Performance Research Group (NASA Ames Research Center 1986)

Dimension	**Definition**
Mental Demand	How much mental and perceptual activity was necessary (e.g., Thinking, deciding, calculating, remembering, looking, etc.)? Whether the task was easy or demanding, simple or complex, exacting or forgiving?
Physical Demand	How much physical activity was necessary (e.g., pushing, pulling, turning, controlling, activating, etc.)? Whether the task was easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal Demand	How much temporal pressure did you feel due to the rate or pace at which the task or task elements occurred? Whether the pace was slow and leisurely or rapid and frantic?
Performance	How successful do you think you were in achieving the goals of the task? How contented were you with your performance in achieving these goals?
Effort	How hard did you have to work or how much effort did you have to exert (mentally and physically) to accomplish your level of performance?
Frustration	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

The link to the survey was sent to three foresters who work in the wildland firefighting realm within the North Carolina Forest Services, a private forest consulting company in North Carolina, and the South Carolina Forestry Commission. Each forester agreed beforehand to distribute the survey link among their firefighting staff, and we received completed responses from 21 firefighting staff. The survey link was emailed on July 31st, 2023, with a deadline for submissions of August 31st, 2023. We received Clemson University Institutional Review Board approval for the survey (IRB 2022-0680).

3.2.2 Data Analysis

We first calculated the descriptive statistics, which were the average overall workload and average workload ratings for each dimension. We used Welch's t-test to compare between prescribed fire and wildfire overall workload ratings. We also conducted a one-way ANOVA to compare the workload ratings between the six dimensions of the NASA TLX. We used the Tukey-Kramer HSD post hoc test to identify which dimension ratings were significantly different compared to other dimensions. We also used Analysis of Covariance (ANCOVA) to compare the overall workload between prescribed fire and wildfire, controlling the effect of age, years of experience in firefighting and the size of the fire. Before conducting the analysis, we checked for the normal distribution of our data and evaluated the assumptions of independence and homogeneity of variance. We analyzed data using R and Microsoft Excel.

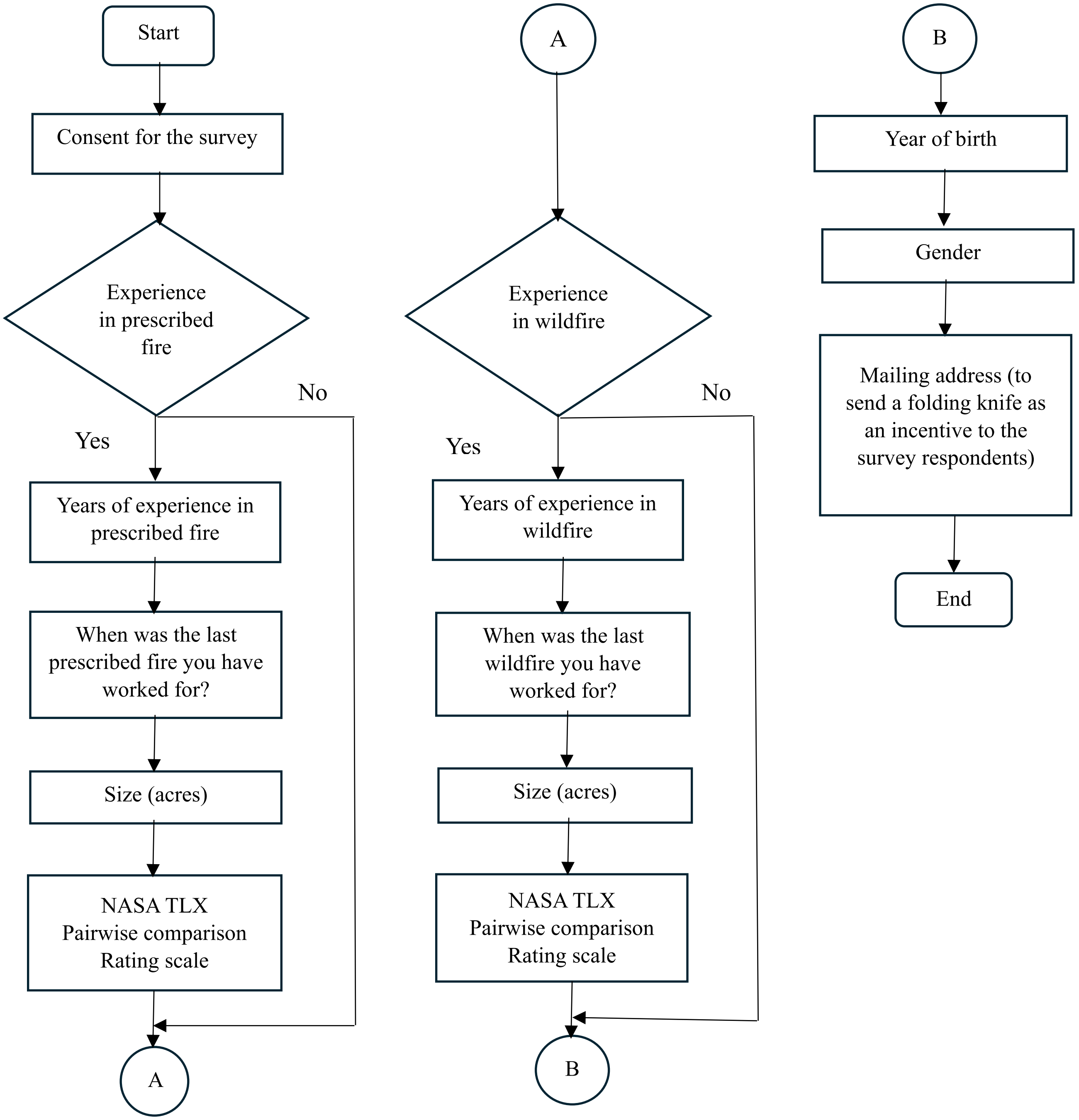


Figure 3. 1: Flow chart of the Qualtrics survey provided to the fire workers

3.3 Results

We received a total of 21 responses to the survey. All 21 respondents had experience working with prescribed fires, and 15 also had experience working with wildfires. Of the 21 respondents, 19 identified their gender as male, one as female, and one preferred not to say. The age of the survey respondents ranged from 23 to 64 years old (Table 3.2). The experience working with prescribed fires ranged from 1 year to 45 years, with a median of 7 years (Table 3.2). The experience with wildfires ranged from 4 years to 35 years, with a median of 15 years. The most recent largest prescribed fire reported was 200 acres, and the smallest was 5 acres, with a median of 60 acres, while the smallest wildfire reported was 0.25 acres, and the largest was 13,000 acres, with a median of 25 acres (Table 3.2). The most recent prescribed fire that the respondents worked on occurred between March 2019 and April 2023, while most of the recent wildfire respondents worked on occurred between October 2022 and July 2023, but there are two responses where their most recent wildfire experience was in October 2005 and April 2016.

Table 3. 2: Demographics and the size of fires according to the responses for prescribed fire and wildfire experience of fire professionals collected using Qualtrics survey (Avg = Average, Min = Minimum, Max = Maximum)

	Prescribed Fire (n=21)					**Wildfire (n=15)**				
	Avg	**CV%**	**Min**	**Max**	**Median**	**Avg**	**CV%**	**Min**	**Max**	**Median**
Age (years)	39	29	23	64	35	45	24	26	64	46
Years of Experience (years)	12	95	1	45	7	15	60	4	35	15
Size of land (acres)	72	68	5	200	60	1235	283	0.25	13,000	25

All respondents gave the highest workload ratings to the Effort and Physical Demand workload dimensions for both prescribed fire and wildfire. In contrast, the lowest rating was given to the Performance workload dimension, indicating that performance has the lowest contribution to the workload (Figure 3.2). This indicates that even though the task was physically challenging and needed much effort, the workers were satisfied with their task accomplishment. The average overall workloads at prescribed fire and wildfire events were 58.89 and 52.20, with no significant difference ($p=0.313$) (Figure 3.2).

For each of the six workload dimensions, there was no significant difference ($p>0.05$) between the workload for prescribed fire and wildfire (Figure 3.2). There was also no significant difference between the workload at prescribed fire and wildfire events after controlling for the effect of the covariates age ($p=0.291$), years of experience ($p=0.301$), and size (acres) of the fire ($p=0.305$).

As there was no difference in workload between prescribed fire and wildfire fire workers, we combined all workload responses from prescribed fire and wildfire to see if any single workload dimension adds significantly more to the overall workload of fire workers (Figure 3.3). Performance is significantly different from all other dimensions and had a considerably lower impact on the workload than any other dimension. The low average of the Performance dimension indicates that most fire workers are satisfied with their performance and how well they have achieved their goals while working with prescribed fires and wildfires. The Effort, Mental Demand and Physical Demand workload dimensions, however, contributed the most to the overall workload of the forest fire workers, indicating that they have to work hard to accomplish that performance level, and the task is laborious and needs a higher level of cognitive activity. Frustration is comparatively lower than other dimensions except the Performance dimension, and Frustration is significantly different from Effort, Physical Demand and Mental Demand dimensions.

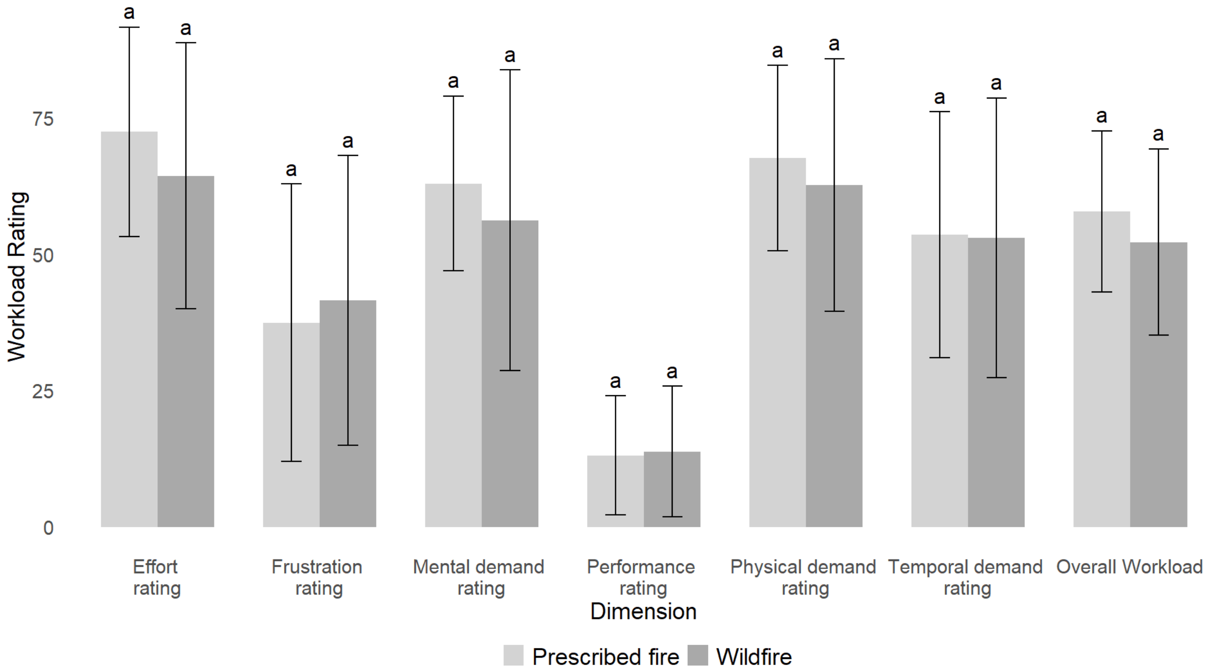


Figure 3. 2: Average overall workload and workload dimension ratings (Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, Frustration) for fire workers for prescribed fire (n=21) and wildfire (n=15). The letters above the bars show the statistical difference between the mean workload ratings for each dimension and the overall workload of fire workers for prescribed fires and wildfires.

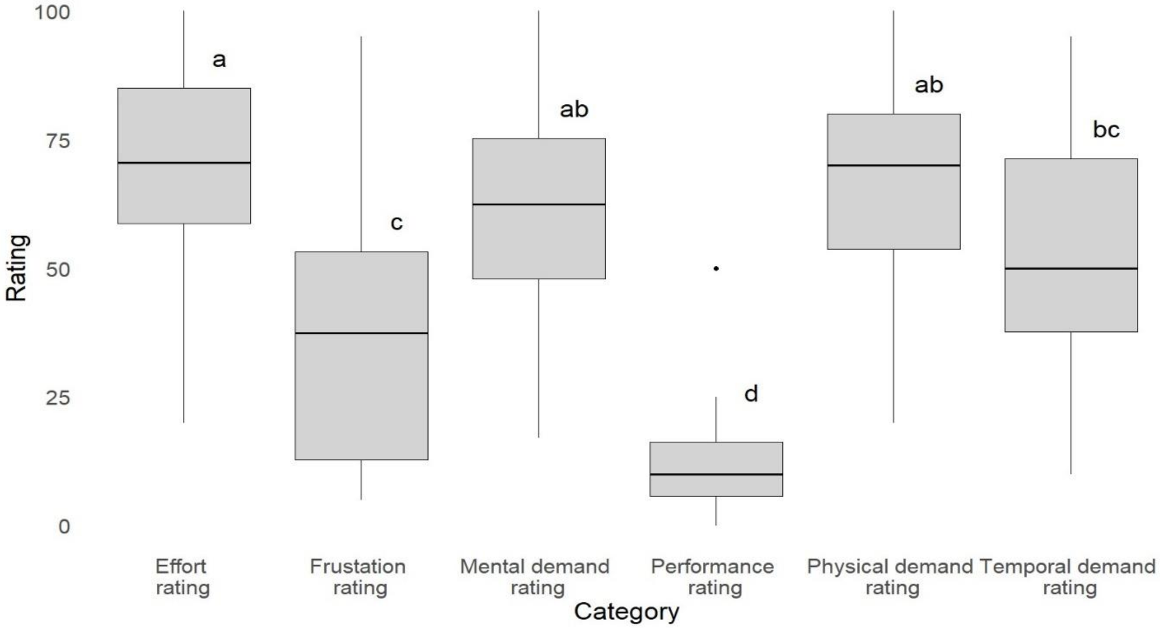


Figure 3. 3: Boxplot of the workload ratings by workload dimensions for all prescribed fire and wildfire responses given by the 21 respondents (Prescribed fire responses (n=21) and wildfire responses (n=15)). The letters above the box show statistical differences between dimensions.

3.4 Discussion

Firefighters work under demanding conditions for long hours. The Occupational Safety and Health Administration (OSHA) has published regulatory limits for exposure to toxic substances that cause respiratory toxicity in firefighters. Also, there are policies implied by OSHA for occupational stress (Batista-Taran and Reio 2011). However, no specific policies are introduced focusing on the workload of forest fire professionals. There are only a limited number of studies conducted on the workload of forest fire professionals, and studying their workload is important in implementing policies and decision-making to safeguard their occupational health. This study is a pilot study aimed at assessing the workload of forest fire workers in North and South Carolina working in prescribed fires and wildfires.

In this study, the overall workload and the workload ratings for the dimensions of forest fire workers were not significantly different between prescribed fire and wildfire. The study by Reisen et al. (2011) states that forest fire workers face a lot of hazards, mainly exposure to toxic air. However, we found only a few studies measuring the physical workload of wildland firefighters (Apud and Meyer 2011; Phillips et al. 2012). Apud and Meyer (2011) conducted a study to synchronize various activities with the percent cardiovascular load to measure their physical workload during actual firefighting, and the results showed that firefighters have a heavy physical workload. (Phillips et al. 2012) identified the physically demanding tasks of rural Australian firefighters. They interviewed firefighters, reviewing 53 tasks that could be performed during bushfire suppression and identified seven tasks to be physically demanding. There were no studies conducted in the United States that compared the mental and physical workload of wildland firefighters and prescribed fire workers.

3.4.1 Workload of Fire Professionals

Effort, Physical Demand and Mental Demand contributed to the overall workload when considering the overall workload of all prescribed fire and wildfire fire workers together. This could be because they have to work in extremely hazardous conditions, including working in the heat and smoke with stress, fatigue and high physical demand (Reisen et al. 2011). Apud and Meyer (2011) identified that the longer the duration of the fire, the heavier the cardiovascular load of fire fighters as it exerts high demands. Also, they have identified that the slope of the terrain and the weight of fuel, which was measured in kilograms, is another important aspect that determines the intensity of work rather than the size or species of tree and the number of firefighters working in line simultaneously affect the workload of firefighters (Apud and Meyer 2011). According to Phillips et al. (2012), there were seven tasks out of fifty-three that were conducted on the fireground identified to be physically demanding for Australian rural wildland firefighters, which are three tasks involved using the hose and four using hand tools. Sudden exposure to toxic smoke from a fire can also affect the immediate performance and decision-making abilities of firefighters (Reisen et al. 2011). Performance contributed the lowest to the overall workload, proving that the fire workers believed that they were very successful in accomplishing the task they were asked to do. This means they could control or put off the fire as they planned. Prescribed fire is also challenging because, if the conditions are severe, it can damage resources intended to benefit from it. If a prescribed fire escapes its planned boundaries, it becomes a wildfire, making the task more challenging (Waldrop and Goodrick 2012). The contribution of Frustration is comparatively lower than all the dimensions except Performance, which proves that fire professionals are content or satisfied with their work. Mapis (2011) states that wildland firefighters feel frustrated when they feel like they are not contributing well or their skills are not being used well. Temporal demand is comparatively lower than effort, Mental Demand, and Physical Demand but higher than Performance and Frustration. This could be because they sense a degree of time pressure as they need to manage time skillfully to suppress fires. Nazari et al. (2020) state that firefighters have to conduct a lot of tasks in a limited time, which can put them under time pressure. However, the temporal demand of wildland firefighters needs to be evaluated in terms of the tasks they conduct at wildfires and prescribed fires.

Studying the workload of prescribed fire and wildfire professionals is crucial to safeguard their health and safety. Despite their extensive training, which helps them to perform well, they have to work under hazardous conditions with high heat, smoke, stress and fatigue. Training sessions are important to equip them to face these challenges while maintaining good physical and mental health. Also, we recommend conducting additional research on the implications of policy and regulations regarding the excessive workload of fire professionals.

3.4.2 Limitations

Several constraints to this study are important to outline. The study was conducted through a Qualtrics survey prepared using the NASA TLX, which is a subjective method. Therefore, the fire worker responses are subjective and prone to recall bias. Respondents always have experiences with different types of emotions that can affect the survey (Spinelli et al. 2020;

Szewczyk et al. 2020). Furthermore, they can have a pre-defined definition for the workload, which makes their responses biased (Hart and Staveland 1988). There were two wildfire responses given by recalling their experience from fires in 2005 and 2016. Another limitation is that the data was not collected on-site while they were performing the work. Therefore, they have to recall the work environment and the workload they felt, introducing a recall bias.

3.5 Conclusions

This study evaluates the workload of forest fire workers in the southern United States. Forest workers who control forest fires play a vital role in forest management, reducing hazardous fuel, conducting prescribed burning and preventing wildfires. Forest fire professionals must do heavy physical work under hazardous conditions in extreme heat and smoke, inhaling toxic air, causing them to have stress and fatigue. Therefore, it is important to study the workload of forest fire workers to understand their working conditions and make necessary improvements. A Qualtrics survey, including the NASA Task Load Index, was used to collect data from fire professionals who participated in prescribed burning and wildfire suppression. Out of the 21 responses, all 21 fire professionals have participated in prescribed burning, and only 15 have participated in wildfires. According to the results, there was no significant difference between the workload of forest fire workers working in prescribed fires and wildfires. Effort, Physical Demand, and Mental Demand were identified as the major contributors to the overall workload of forest fire workers, while Performance played a minor role. This suggests that people are satisfied with the accomplishment of their tasks. However, they have to put in a lot of Physical and Mental Demands and Effort to complete the tasks. Therefore, it is important to conduct additional research on the workload of forest firefighters in order to increase awareness of occupational health factors and improve fire management.

CHAPTER FOUR

CONCLUSION

4.1 Chapter One Conclusion

The goal of Chapter 1 is to provide an overview of the research conducted so far and to identify the gaps and areas that still require investigation on workload to accurately measure the workload associated with forest activities to safeguard the health and safety of forest equipment operators.

I studied this using two main databases, Google Scholar and Web of Science (WoS), and determined the types of articles available on the workload of forest equipment operators. I screened the research articles and selected the most suitable studies. Then, those articles were sorted according to the harvesting method used by the equipment operators, the method used to measure the workload, and different stand conditions. Then, I provide a detailed description of studies conducted on the workload of forest equipment operators to help find the knowledge gaps in which more studies should be conducted, especially in the United States, to certify a healthy working environment for forest equipment operators.

This literature review identified several techniques used in measuring workload in different sectors. Some of these methods were also used in the forestry sector. Two main techniques are used to measure workload (both physical and mental): subjective and objective. Several subjective workload measuring techniques were used in workload assessments conducted in the forestry sector, such as NASA TLX, Chalder Fatigue Scale and Nordic Standardized

Questionnaire. Also, several studies assessing workload used objective methods such as heart rate, blood oxygen demand, heart rate variability, and eye movement tracking.

However, most of these studies were conducted in Europe, studying mental strain, physical workload, and musculoskeletal disorders. Few studies were conducted in the North American region in the workload sector calculating the logging injury rate, assessing the worker awareness of using exoskeletons, the physical workload of chainsaw operators, exposure to vibration and noises, and the impact of extended working hours. Several studies were also reported from other regions of the world, such as New Zealand, Turkey, Iran and Tanzania. These studies have focused on the physical workload of logging equipment operators, forest industry employees, and cable hauler choker setters.

4.2 Chapter Two Conclusion

Chapter 2 aims to assess the workload of the logging equipment operators operating conventional wheeled feller-buncher, grapple skidder, and knuckle-boom loader harvesting systems in the southern U.S. using South Carolina as a proxy.

I studied this using both subjective and objective methods. I used the NASA TLX method to evaluate the overall workload. I collected data at seven logging sites from 19 equipment operators. Both rating scales and pairwise comparisons were done. Each operator ranked the importance of each dimension and rated each dimension. The six dimensions were physical Demand, Mental Demand, Temporal Demand, Performance, Effort, and Frustration. Using the ratings and the weights, the overall workload was calculated. We also collected demographic information of operators, such as gender, age, height, weight, logging experience, experience with machine type, and a yes/no question about any health conditions. I collected heart rates and video recordings for all logging equipment operators. To collect heart rate data, I asked the operators to wear a Polar Verity Sense Model 4J heart rate monitor armband on their forearms below the elbow while working. Then, I mounted a GoPro Hero camera using a suction cup on the windshield of the equipment to record the activities these equipment operators do simultaneously to the heart rates for about 90 to 120 minutes.

Welch's t-test comparing the overall workload ratings between clearcut and thinning sites showed no significant difference. I also conducted a one-way ANOVA comparing the workload ratings between the six dimensions of the NASA TLX and used the Tukey-Kramer HSD for a post hoc comparison. I observed that Effort, Frustration and Temporal Demand dimensions contributed the most to the overall workload, while Performance contributed the least. I used ANCOVA to compare the overall workload values between clearcut and thinning sites, considering the effects of BMI and the age of the operators on the overall workload, and no significant difference was observed. According to the heart rate variations, there were several sudden heart rate increases observed, which occurred mainly due to conducting physical activities or due to a sudden increase in the complexity of the task, such as cleaning the debris from the sawblade, trimming branches off from trees loaded to log truck and loading logs to two log trucks consecutively. It is recommended to have organized breaks between complex tasks to prevent the excessive workload on equipment operators. More studies are recommended to be conducted to evaluate the workload of logging equipment operators in the southern United States to safeguard the health and safety of equipment operators.

4.3 Chapter Three Conclusion

Chapter 3 aims to assess the workload of forest fire workers in the southern United States by evaluating the subjective workload of forest fire workers in North and South Carolina working in prescribed fires and wildfires. I used an online survey developed using the Qualtrics platform, which included questions related to three parts: experience working prescribed fires, experience working wildfires and demographic questions. I received 21 responses from people with prescribed fires experience and 15 responses from people with wildfire experience.

I conducted Welch's t-test to compare prescribed fire and wildfire overall workload ratings, and there was no significant difference. According to the ANOVA test, one or more dimensions contribute more to the overall workload. The Tukey HSD test indicated that Performance had a significantly lower impact on the overall workload, and the Effort, Mental Demand and Physical Demand workload dimensions, however, contributed the most to the overall workload. I also conducted the ANCOVA test to compare the overall workload between prescribed fire and wildfire, controlling the effect of age, years of experience in firefighting and the size of the fire, and there was no significant difference between the workload at prescribed fire and wildfire events. This research shows the importance of conducting more studies to assess the workload of fire professionals working with prescribed fires and wildfires in the United States to safeguard the health and safety of fire professionals.

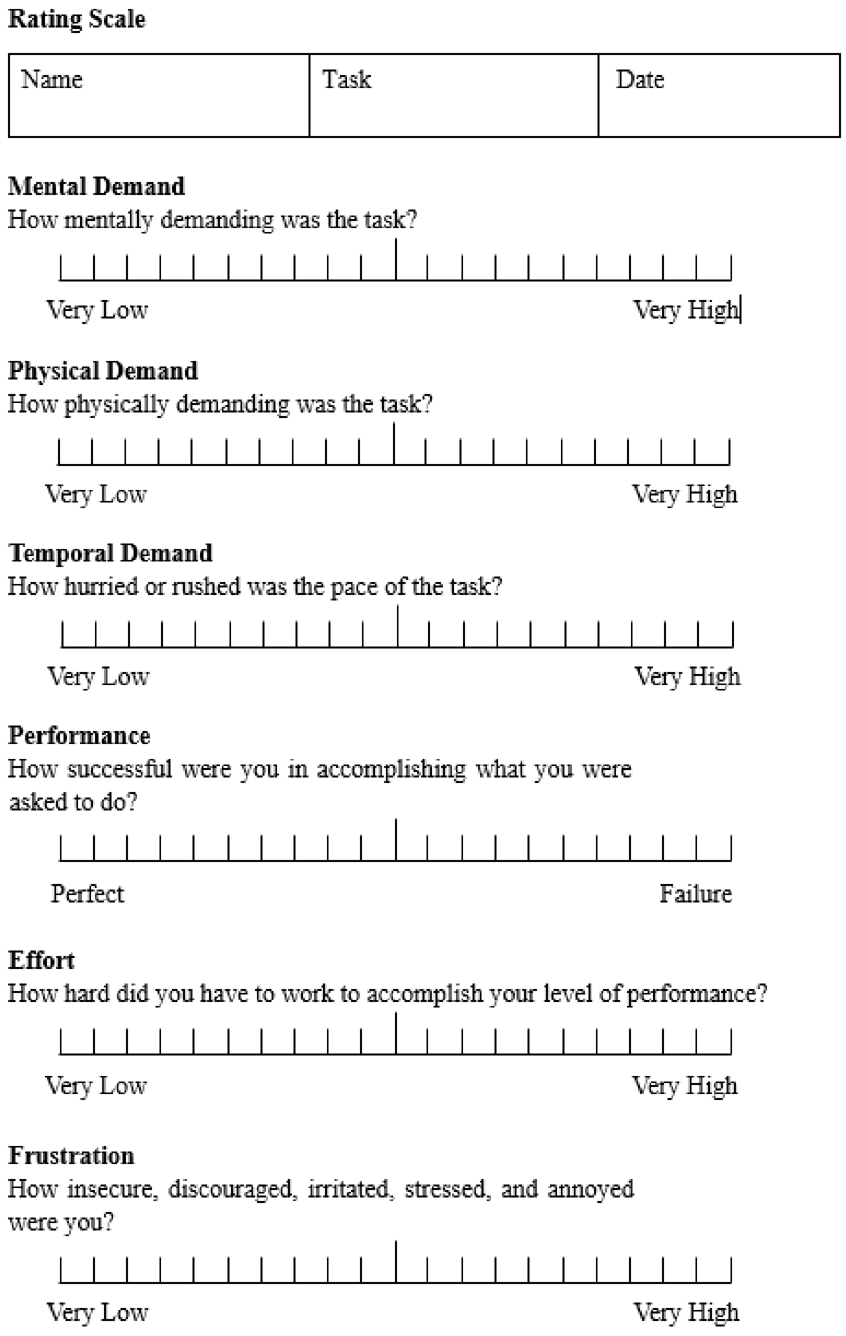
The findings of this study reveal some important factors regarding the workload among forestry professionals. According to the NASA TLX, the factors affecting the workload of forest equipment operators are Effort, Frustration and Temporal Demand. At the same time, physical activities and an increase in task complexity increased heart rates, indicating an increment in workload. It is recommended to have organized rest times when conducting complex tasks. However, according to the NASA TLX study, for forest fire professionals, the factors mostly affecting the overall workload are Effort, Mental Demand and Physical Demand. Organizing training sessions to equip them to face these challenges while maintaining good mental and physical health. Therefore, it is evident there are several factors that increase the workload of forestry professionals that need to be studied in depth.

4.4 Overall Conclusion

There is a lack of studies conducted in the United States to assess the workload of forest equipment operators, especially for the conventional harvesting system in the southern United States, which includes the wheeled feller-buncher, grapple skidder and knuckle-boom loader. There were only a few studies conducted so far to assess the workload of fire professionals working with wildfire and prescribed fire. With the challenging environment they work in, it is important to assess their physical and mental strain.

APPENDICES

Appendix A



Rating Scale

Name	Task	Date

Mental Demand

How mentally demanding was the task?

Very Low Very High

Physical Demand

How physically demanding was the task?

Very Low Very High

Temporal Demand

How hurried or rushed was the pace of the task?

Very Low Very High

Performance

How successful were you in accomplishing what you were asked to do?

Perfect Failure

Effort

How hard did you have to work to accomplish your level of performance?

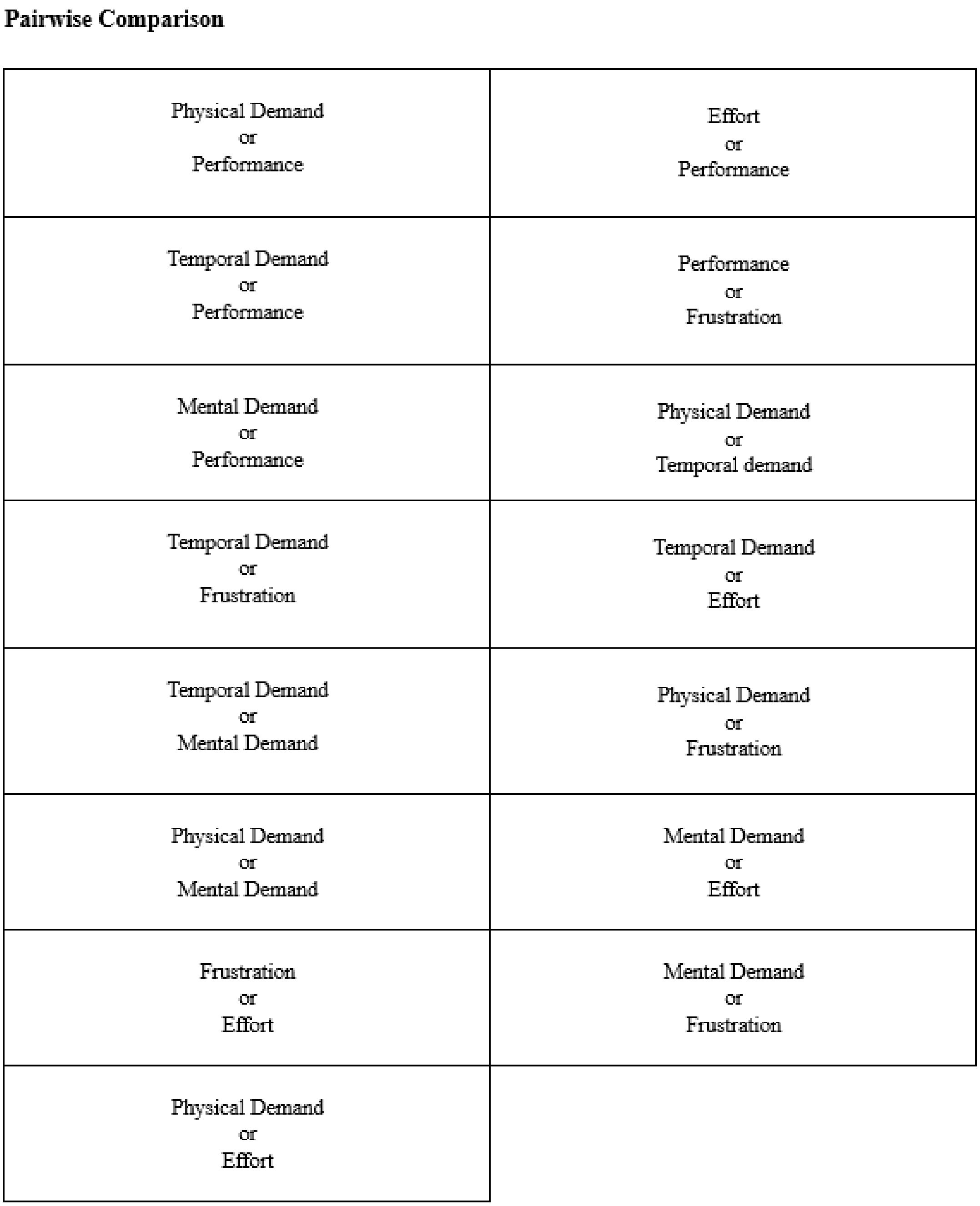
Very Low Very High

Frustration

How insecure, discouraged, irritated, stressed, and annoyed were you?

Very Low Very High

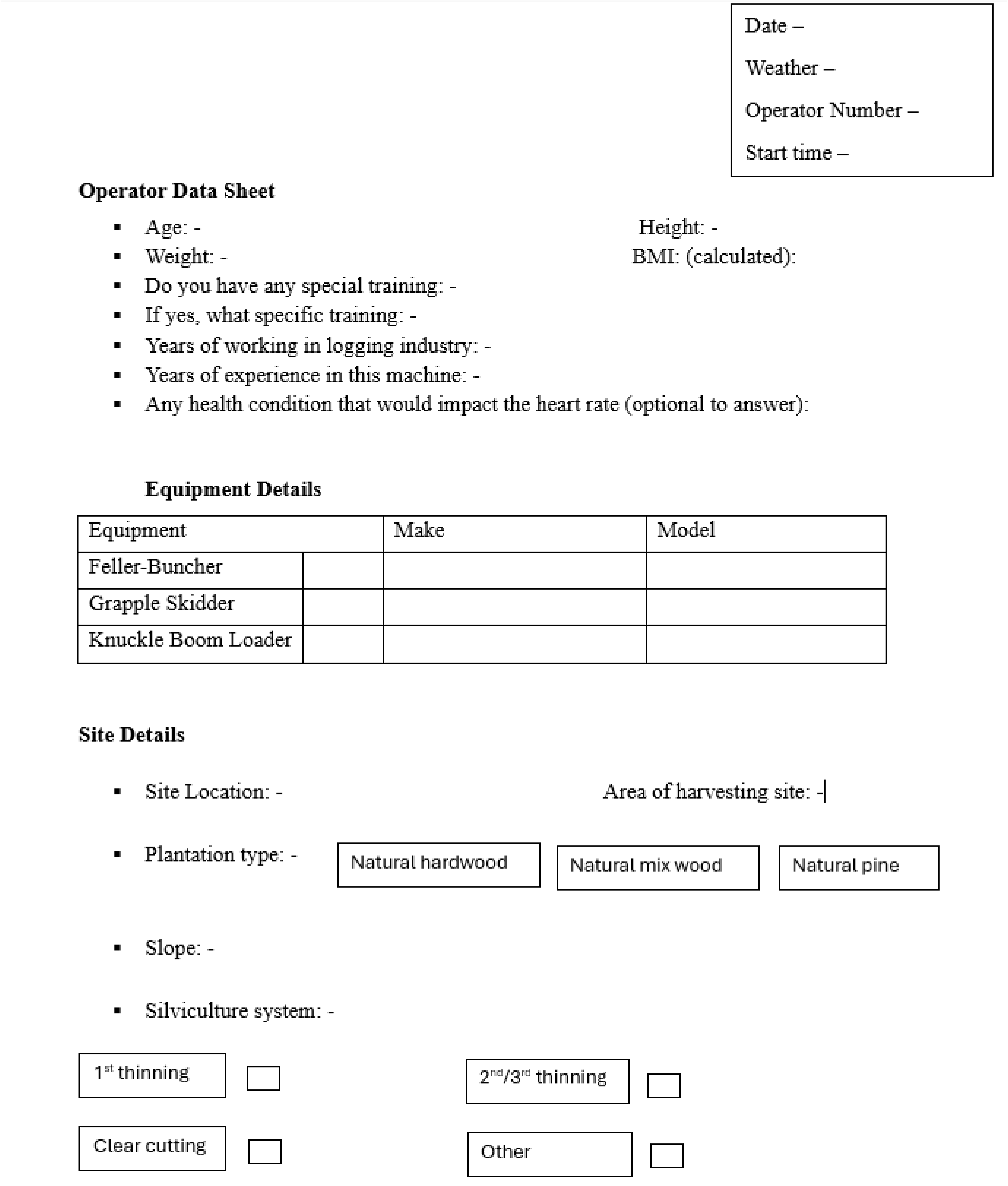
Figure A. 1: NASA Task Load Index rating scale



Pairwise Comparison

Physical Demand or Performance	Effort or Performance
Temporal Demand or Performance	Performance or Frustration
Mental Demand or Performance	Physical Demand or Temporal demand
Temporal Demand or Frustration	Temporal Demand or Effort
Temporal Demand or Mental Demand	Physical Demand or Frustration
Physical Demand or Mental Demand	Mental Demand or Effort
Frustration or Effort	Mental Demand or Frustration
Physical Demand or Effort	

Figure A. 2: NASA Task Load index pairwise comparison



Date –

Weather –

Operator Number –

Start time –

Operator Data Sheet

- Age: - Height: -
- Weight: - BMI: (calculated):
- Do you have any special training: -
- If yes, what specific training: -
- Years of working in logging industry: -
- Years of experience in this machine: -
- Any health condition that would impact the heart rate (optional to answer):

Equipment Details

Equipment		Make	Model
Feller-Buncher			
Grapple Skidder			
Knuckle Boom Loader			

Site Details

- Site Location: - Area of harvesting site: -
- Plantation type: - Natural hardwood Natural mix wood Natural pine
- Slope: -
- Silviculture system: -

1st thinning ☐ 2nd/3rd thinning ☐

Clear cutting ☐ Other ☐

Figure A. 3: Logging equipment operator datasheet

Appendix B

Table A. 1: Qualtrics Survey for Forest Fire Professionals

Q1. Do you have experience working on a prescribed fire burning?

○ Yes ○ No

Q2. If yes, when was the last prescribed fire burning you participated

	Month	Year
Please select:		

Q3. Area of the prescribed fire burned land (in acres)

Q4. The following questions are from the NASA Task Load Index Survey. For all answers, please consider the last prescribed fire you worked on. NASA Task Load Index is a two-part evaluation procedure consisting of a rating scale with six subscales given and a pairwise comparison of the considered six factors.

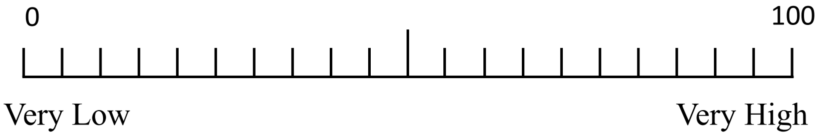
The first part of the questions will ask you to evaluate the contribution of each of the six factors to the overall workload using a rating scale from low to high. The second part will ask you to pick one factor from a pairwise comparison that contributes most to your overall workload.

Q5. For each of the six factors below, please rate your workload during the last prescribed fire you worked on.

Q6. **Mental Demand**

How mentally demanding was your last prescribed fire?

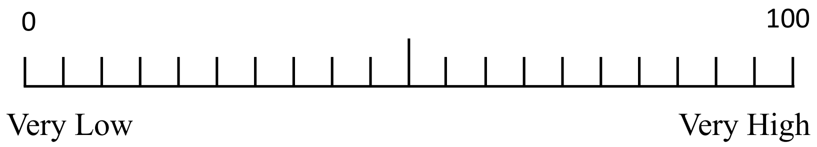
How much mental or perceptual activity was required (thinking, deciding, calculating, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving? (0 = low mental demand; 100 = high mental demand)



Q7. **Physical Demand**

How physically demanding was your last prescribed fire?

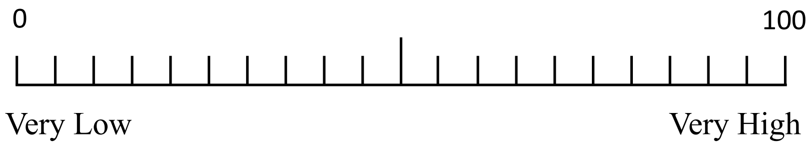
How much physical activity was required? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious (0 = low physical demand; 100 = high physical demand)



Q8. **Temporal Demand**

How hurried or rushed was the pace of your last prescribed fire?

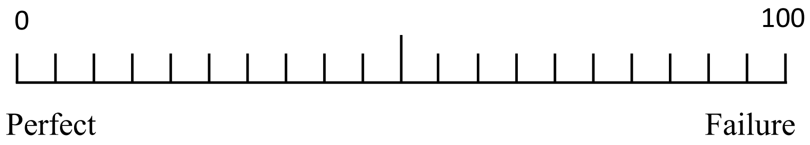
How much time pressure did you feel due to the rate or pace the task or task elements occurred? Was the pace fast or frantic? (0 = low temporal demand; 100 = high temporal demand)



Q9. **Performance**

How successful were you in accomplishing what you were asked to do in the last prescribed fire?

How successful do you think you were in accomplishing the goal of the task? How satisfied were you with your performance in accomplishing these goals? (0 = poor performance; 100 = good performance)



Q10. **Effort**

How hard did you have to work to accomplish your level of performance in the last prescribed fire?

How hard did you have to work (mentally and physically) to accomplish your level of performance? (0 = low effort; 100 = high effort)

0 100

Very Low Very High

Q11. **Frustration**

How insecure, discouraged, irritated, stressed, and annoyed were you during the last prescribed fire?

How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task? (0 = low frustration; 100 = high frustration)

0 100

Very Low Very High

Q12. Next, from a pairwise comparison, you will select the one factor that added the most to your overall workload.

In the pairwise comparison, there are 15 possible pairs using the six factors from before. You need to highlight one factor out of each pair that contributed more to the workload of the last prescribed fire you worked on.

Q13. Select the factor that contributed the most to your overall workload during the last prescribed fire you worked on.

○ Physical Demand

○ Performance

Q14. Select the factor that contributed the most to your overall workload during the last prescribed fire you worked on.

○ Effort

○ Performance

Q15. Select the factor that contributed the most to your overall workload during the last prescribed fire you worked on.

○ Temporal Demand

○ Performance

Q16. Select the factor that contributed the most to your overall workload during the last prescribed fire you worked on.

- ○ Performance
- ○ Frustration

Q17. Select the factor that contributed the most to your overall workload during the last prescribed fire you worked on.

- ○ Mental Demand
- ○ Performance

Q18. Select the factor that contributed the most to your overall workload during the last prescribed fire you worked on.

- ○ Physical Demand
- ○ Temporal Demand

Q19. Select the factor that contributed the most to your overall workload during the last prescribed fire you worked on.

- ○ Temporal Demand
- ○ Frustration

Q20. Select the factor that contributed the most to your overall workload during the last prescribed fire you worked on.

- ○ Temporal Demand
- ○ Effort

Q21. Select the factor that contributed the most to your overall workload during the last prescribed fire you worked on.

- ○ Temporal Demand
- ○ Mental Demand

Q22. Select the factor that contributed the most to your overall workload during the last prescribed fire you worked on.

- ○ Physical Demand
- ○ Frustration

Q23. Select the factor that contributed the most to your overall workload during the last prescribed fire you worked on.

○ Physical Demand

○ Mental Demand

Q24. Select the factor that contributed the most to your overall workload during the last prescribed fire you worked on.

○ Mental Demand

○ Effort

Q25. Select the factor that contributed the most to your overall workload during the last prescribed fire you worked on.

○ Frustration

○ Effort

Q26. Select the factor that contributed the most to your overall workload during the last prescribed fire you worked on.

○ Mental Demand

○ Frustration

Q27. Select the factor that contributed the most to your overall workload during the last prescribed fire you worked on.

○ Physical Demand

○ Effort

Q28. Have you worked on a wildfire in the past?

○ Yes ○ No

Q29. If yes, when was the last wildfire burning you participated?

	Month	Year
Please select:		

Q30. Area of the wildfire burned land (in acres)

☐

Q31. The following questions are from NASA Task Load Index Survey. For all answers, please consider the last wildfire you worked on. NASA Task Load Index is a two-part evaluation procedure consisting of a rating scale with six subscales given and a pairwise comparison of the considered six factors.

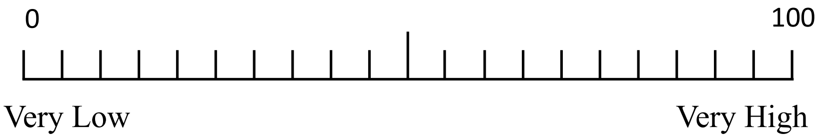
The first part of the questions will ask you to evaluate the contribution of each of the six factors to the overall workload using a rating scale from low to high. The second part will ask you to pick one factor from a pairwise comparison that contributes most to your overall workload.

Q32. For each of the six factors below, please rate your workload during the last wildfire you worked on.

Q33. **Mental Demand**

How mentally demanding was your last wildfire?

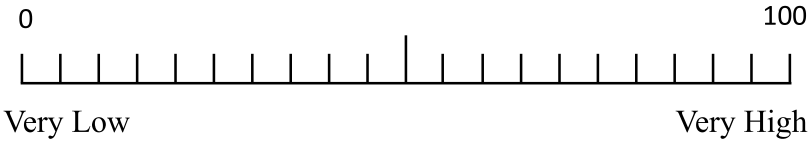
How much mental or perceptual activity was required (thinking, deciding, calculating, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving? (0 = low mental demand; 100 = high mental demand)



Q34. **Physical Demand**

How physically demanding was your last wildfire?

How much physical activity was required? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious (0 = low physical demand; 100 = high physical demand)



Q35. **Temporal Demand**

How hurried or rushed was the pace of your last wildfire?

How much time pressure did you feel due to the rate or pace the task or task elements occurred? Was the pace fast or frantic? (0 = low temporal demand; 100 = high temporal demand)

0 100

Very Low Very High

Q36. **Performance**

How successful were you in accomplishing what you were asked to do in the last wildfire?

How successful do you think you were in accomplishing the goal of the task? How satisfied were you with your performance in accomplishing these goals? (0 = poor performance; 100 = good performance)

0 100

Perfect Failure

Q37. **Effort**

How hard did you have to work to accomplish your level of performance in the last wildfire?

How hard did you have to work (mentally and physically) to accomplish your level of performance? (0 = low effort; 100 = high effort)

0 100

Very Low Very High

Q38. **Frustration**

How insecure, discouraged, irritated, stressed, and annoyed were you during the last wildfire?

How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task? (0 = low frustration; 100 = high frustration)

0 100

Very Low Very High

Q39. Next, from a pairwise comparison, you will select the one factor that added the most to your overall workload.

In the pairwise comparison, there are 15 possible pairs using the six factors from before. You need to highlight one factor out of each pair that contributed more to the workload of the last wildfire you worked on.

Q40. Select the factor that contributed the most to your overall workload during the last wildfire you worked on.

○ Physical Demand

○ Performance

Q41. Select the factor that contributed the most to your overall workload during the last wildfire you worked on.

○ Effort

○ Performance

Q42. Select the factor that contributed the most to your overall workload during the last wildfire you worked on.

○ Temporal Demand

○ Performance

Q43. Select the factor that contributed the most to your overall workload during the last wildfire you worked on.

○ Performance

○ Frustration

Q44. Select the factor that contributed the most to your overall workload during the last wildfire you worked on.

○ Mental Demand

○ Performance

Q45. Select the factor that contributed the most to your overall workload during the last wildfire you worked on.

○ Physical Demand

○ Temporal Demand

Q46. Select the factor that contributed the most to your overall workload during the last wildfire you worked on.

○ Temporal Demand

○ Frustration

Q47. Select the factor that contributed the most to your overall workload during the last wildfire you worked on.

○ Temporal Demand

○ Effort

Q48. Select the factor that contributed the most to your overall workload during the last wildfire you worked on.

○ Temporal Demand

○ Mental Demand

Q49. Select the factor that contributed the most to your overall workload during the last wildfire you worked on.

○ Physical Demand

○ Frustration

Q50. Select the factor that contributed the most to your overall workload during the last wildfire you worked on.

○ Physical Demand

○ Mental Demand

Q51. Select the factor that contributed the most to your overall workload during the last wildfire you worked on.

○ Mental Demand

○ Effort

Q52. Select the factor that contributed the most to your overall workload during the last wildfire you worked on.

○ Frustration

○ Effort

Q53. Select the factor that contributed the most to your overall workload during the last wildfire you worked on.

○ Mental Demand

○ Frustration

Q54. Select the factor that contributed the most to your overall workload during the last wildfire you worked on.

○ Physical Demand

○ Effort

Q55. We would like to ask you a few questions about your background and demographics

Q56. What is your gender?

○ Male

○ Female

○ Non-binary/ third gender

○ Prefer not to say

Q57. In what year were you born?

☐

Q58. How many years of experience do you have working on prescribed fires?

☐

Q59. How many years of experience do you have working on wildfires?

☐

Q60. We would like to thank you for your time spent taking this survey. We would like to send you a Buck folding knife as a small token of appreciation. Please provide your mailing address below. If you do not want to provide the mailing address with your response, you can send an email including the mailing address to phiesl@clemson.edu

☐

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