

Protocol

The Psychophysiological Interrelationship Between Working Conditions and Stress of Harvester and Forwarder Drivers—A Study Protocol

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Abstract

(1) Background: Austria's use of fully mechanized harvesting systems has been continuously increasing. Technical developments, such as traction aid winches, have made it possible to drive on increasingly steep terrain. However, this has led to challenges and potential hazards for the operators, resulting in higher stand damage rates and risks of workplace accidents. Since these systems and working environments involve a highly complex interplay of various parameters, the purpose of this protocol is to propose a new set of methodologies that can be used to obtain a holistic interpretation of the psychophysiological interrelationship between the working conditions and stress of harvester and forwarder drivers. (2) Methods: We developed a research protocol to analyse the (a) environmental and (b) machine-related parameters; (c) psychological and psychophysiological responses of the operators; and (d) technical outcome parameters. Within this longitudinal exploratory field study, experienced drivers were monitored for over an hour at the beginning and the end of their workday while operating in varying steep terrains with and without a traction aid winch. The analysis is based on macroscopic (collected using cameras), microscopic (eye-tracking glasses and AI-driven emotion recognition), quantitative (standardized questionnaires), and qualitative (interviews) data. This multimodal research protocol aims to improve the health and safety of forest workers, increase their productivity, and reduce damage to remaining trees.

Keywords: emotion recognition; eye tracking; electrodermal activity; forwarder; harvester; health; heart rate variability; psychophysiology; safety; stress; traction aid winches



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1. Introduction

Around 48% of the federal territory of Austria is covered by forests and the stock of wood is maintained through sustainable and active forest management [1]. There are several types of timber harvesting systems, which range from a low level of mechanization to being fully mechanized. In the Austrian forestry industry, harvesters and forwarders are used to fell trees and transport the logs to forest roads. In steep terrain, these machines are regularly assisted by traction aid winches to increase machine stability and to reduce soil damage. Using winch-assisted, fully mechanized harvesting systems increases the working safety in steep terrain [2]. However, working in mountainous areas still poses additional

stressors and hazards compared to operating on flat terrain. The main challenges for the operators range from difficulties manoeuvring the machines on uneven terrain to variable soil conditions, which influence the work in progress [3]. The working environment has been shown to have an impact on the operator's mental workload. For example, Szewczyk et al. [4] showed that the driver's mental workload increased when working in conditions with higher slope gradients as they are very aware that they are using the machine at the limits of its capacity while driving through the steepest segments. Holzfeind et al. [5] confirmed that steep terrain is more challenging for operators and leads to lower productivity during winch-assisted logging operations.

1.1. Study Aims

Here, we present a protocol to assess the complex interrelationship between the working conditions and stress of harvester and forwarder drivers. The protocol aims to identify stress-related work situations among harvester and forwarder operators working with and without traction aid winches in terrains of varying steepness by examining environmental, psychological, psychophysiological, and technical parameters in relation to the following three hypotheses: (1) Higher mental stress, mental strain, and psychophysiological arousal increase the damage to the remaining stand; this is assessed using environmental (slope gradient and inclination of the cabin), machine-related (tasks performed by the driver), technical (stand damage rates), psychological (mental stress and mental strain), and psychophysiological (heart rate variability) measures. (2) The ability to concentrate decreases throughout a workday depending on the difficulty of the work; this is measured via environmental (slope gradient and inclination of the cabin) and attention-related physiology (eye fixation duration) measurements. (3) Higher mental stress, mental strain, and psychophysiological arousal reduce productivity; this is evaluated through the integration of environmental parameters, machine-related data, technical parameters (productivity), and psychological and psychophysiological measures. (4) Mental stress, mental strain, and psychophysiological arousal are higher in forwarder drivers compared to harvester drivers.

1.2. A Multimodal Approach

The forest environment, operator, and machine likely influence each another, and psychological parameters, event-related psychophysiological responses, and technical data can serve as measurable outcomes. While most studies have focused on the operator, the machine, or on the influence of the working conditions on the driver, this protocol integrates several perspectives into a single framework (Figure 1).

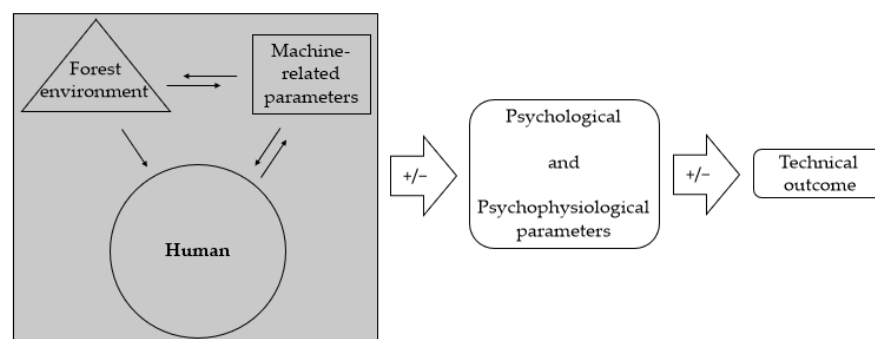


Figure 1. Illustration of the conceptual framework of the multimodal research protocol summarizing the hypothesized interactions between the forest environment, machine-related parameters, and human factors and their measurable outcomes.

2. Background and Operational Context

2.1. Harvester and Forwarder Machines

Technological developments can lead to more efficient harvesting operations with lower rates of damage to trees in the remaining stand [6,7]. Bogie tracks and traction aid winches, originally designed to decrease the negative impacts of heavy machinery on the soil, now allow for operations on steep terrain with slope gradients of 60% and higher depending on the soil properties and configuration of the machines [8,9]. In contrast to motor-manual harvesting systems, fully mechanized systems reduce the number of serious injuries to operators as they are protected by the safety structure of the cabin [2,7,10]. Fully mechanized harvesting systems are gaining importance in the Austrian forestry industry. The proportion of timber extracted by forwarders increased from 33% of the total annual cut in 2012 to 39% in 2022. The high quantity of the new harvesters and forwarders owned by forest entrepreneurs (produced within the last 5 years) highlights the potential of this technology in the near future [11,12]. Socioeconomic reasons, such as comparatively high labour costs, are driving the shift towards a higher proportion of fully mechanized harvesting systems in use in Austria. However, there are more factors affecting the operators of these systems. Here, the mental stress, mental strain, and psychophysiological arousal that drivers experience while operating these heavy machines under partially extreme environmental conditions is of particular interest.

2.2. Self-Reported Psychological States

Mental workload, strain, stress, fatigue, and subjective well-being are interrelated but distinct psychological outcomes. Their accurate definition is essential to interpreting the results correctly and deriving treatment and diagnosis recommendations. However, it should be noted that defining these terms is challenging due to differences in language since some questionnaires are only available in German.

Mental stress is defined as “all assessable influences impinging upon a human being from external sources and affecting that person mentally” according to the definition of the ISO 10075 standard [13], (p. 6). Mental strain is the immediate effect of mental stress on the individual depending on their current condition. “Mental workload” in this definition is considered as umbrella term encompassing mental stress and mental strain. Mental stress is compatible with the use of the term “work stress” which is synonymously used with the term “external workload” [13].

A high external workload is regarded as an important but not critical factor in the development of stress reactions [14]. It is possible to work hard in a demanding environment without experiencing mental strain.

Mental fatigue and stress response, as well as monotony and mental satiation, are examples of the negative consequences of mental strain [13,15]. Mental fatigue is discussed from several perspectives in the literature (e.g., [14]), which differentiates between tiredness, fatigue, and exhaustion. If exhaustion intensifies, it results in a chronic loss of energy and fatigue, which is characterized by cognitive, emotional, and physical symptoms [16]. In this protocol, we focus on mental fatigue and stress response within the mental strain concept.

Finally, subjective well-being (SWB) is, in contrast to the other terms, a very broad concept and is used across different disciplines [17]. Diener [18] described it as a person thinking and feeling that their life is desirable, no matter how others view it. SWB is affected by external and internal factors. Determinants, such as personal goals, activities, health factors such as quality of sleep, emotions, and needs, influence subjective well-being [17].

2.3. Factors Influencing Psychological and Technical Parameters

Several other factors, such as cabin rotation, traction aid winch use, slope gradient, and soil conditions, influence the driver's mental stress, mental strain, psychophysiological arousal, productivity, and safety.

The machine specifications—the model, age, and/or technical condition of the harvester or forwarder—are also important. Cabin rotation and cabin tilt were found to enhance visibility during harvesting operations, thereby improving productivity and reducing the mental workload [19,20].

Additionally, the choice of bogie tracks and the use of traction aid winches are crucial for the driver's well-being while the duration and schedule of work shifts and weather and visibility conditions affect the rate at which mental fatigue develops [20].

The most dreaded situation for harvester and forwarder operators is tipping or rolling over. For machines working with traction aid winches, this could occur due to a rope failure, a traversal slope, or compromised positions. The use of traction aid winches has resulted in a decrease in the number of accidents, but new hazards and stressful situations can occur because these winches allow for operations on even steeper slopes [10]. Soil properties affect the trafficability and stability of machinery on steep slopes, consequently affecting the operator. Rutting depth and wheel slippage are dependent on various soil properties such as soil texture, moisture, organic matter content, and the slope of the terrain [21].

2.4. Assessment of Psychophysiological Parameters

Environmental parameters (such as soil conditions and slope gradient) can provide insights into the driver's psychological and psychophysiological state. Combining these with subjective and objective psychophysiological (qualitative interviews and quantitative questionnaires), and machine-related parameters (performed tasks) can yield a comprehensive picture of the driver's psychophysiology.

The discipline of psychophysiology is based on two assumptions: (1) human emotion, thought, perception, and action are physical phenomena embedded in human consciousness, and (2) the responses of the brain and body can explain human processes through the use of an appropriate experimental design [22]. Key psychophysiological indicators include heart rate variability, eye fixation duration, cortisol level, electrodermal activity (EDA), arousal, and facial expressions.

2.4.1. Heart Rate Variability (HRV)

A complex working environment can impact mental workload and work performance. Spinelli et al. [23] conducted interviews and measured the HRV of harvester operators and found that subjective performance contributed to mental workload, which increased when passing from pure conifer to mixed stands.

The beating heart generates electrical activity that can be measured using electrodes through electrocardiography (ECG). A heartbeat can be split into three waves, and one part, the R wave, represents the spike. Thus, the heart rate reflects the frequency of all these parts. HRV is defined as the physiological change in the interval between R waves or the RR interval. Under emotional stress, there is lower variability between the R intervals, i.e., the HRV decreases. There are other devices that can be used to monitor HRV, including pulse oximeters, which are put on the finger or ear, or wearables, such as wristbands and watches. Most of these devices depend on the optical technique called photoplethysmography (PPG). However, ECG electrodes used in chest straps are more accurate than PPG sensors [24,25].

2.4.2. Eye Tracking

Screen-based eye-tracking devices and mobile eye-tracking glasses can be used to record eye movements and activity. The most commonly used metrics for the measurement of visual interest and attention are fixations and saccades. While fixation duration is the amount of time that a person looks at a specific object and saccades are the eye movements between fixations [26].

Galley et al. [27] investigated why fixation durations differ. They suggested two factors that impact fixation duration, namely mental effort and difficulty of the task. The more difficult the task is, the longer the fixations. Furthermore, they noted that if a task is more difficult, fixations shorter than 90 ms are impeded since such irrelevant behaviour is inhibited. If someone needs to concentrate on a difficult task, more mental effort is required, and the fixation duration increases. Low competence also corresponds to a longer fixation duration. Age has an even greater effect: as age increases, mental processes require more time to complete and therefore fixation duration increases. Lastly, the authors categorized fixations into very short fixations, which cannot be consciously and cognitively controlled; express fixations, which are longer and therefore allow little time for cognitive processes to occur; cognitive fixations, which are associated with inhibition, signifying cognitive control and attention; and very long fixations [27].

De Rivecourt et al. [28] analysed pilots while they trained using a fixed-base flight simulator. HRV data was collected using a chest strap, fixation duration was determined by measuring eye activity, and a rating scale was used to assess mental stress while performing different tasks. As the task load increased, the heart rate increased while the HRV and the fixation duration decreased [28]. Assessment of mental workload in real-life settings was performed by analysing saccade duration obtained from mobile eye trackers, which were calibrated prior to use. When comparing logging categories, Naskrent et al. [20] described higher levels of mental workload for harvester operators working in clear-cuts compared to windbreaks or thinning operations. Using a device that tracks the dominant eye of the participant, eye fixation duration was found to increase with increasing mental workload [29]. Finally, Szewczyk et al. [30] divided the recorded video data based on the four different work activities and analysed both saccades and fixation duration to determine the driver's mental workload [30].

2.4.3. Cortisol

Cortisol is a hormone that plays an important role in the human body; it is responsible for the physiological changes to respond and adapt to stress [31].

Veltman and Gaillard [32] evaluated the HRV and cortisol levels using saliva samples from experienced pilots as indicators of mental workload. They found that their HRV was reduced while flying in more complex scenarios, whereas their cortisol levels slightly increased. The average cortisol levels over the last 1–2 months can also be analysed using one to two centimetres of a hair sample collected from the head [33]. van der Meij et al. [34] suggested that a high hair cortisol concentration correlates with a high mental workload and self-reported stress at work.

2.4.4. Arousal and Electrodermal Activity

EDA is an important measure in the field of psychophysiology [35]. Emotional arousal, such as stress, can be measured by examining the changes in skin conductance, generally defined as EDA. Within the skin are sweat glands, and whenever they are triggered by an emotional stimulus, they release moisture. The changes in the levels of negative and positive ions in the sweat results in the current flowing more easily, and these changes can be observed as changes in skin conductance. Emotional sweating occurs during

certain emotional states such as stress or strong arousal [36]. Thus, being exposed to a fearful stimulus induces emotional arousal, which causes increased sweat secretion and a higher EDA. Electrodermal recordings are divided into several units. One of these refers to responses, phasic phenomena (electrodermal response), or the skin conductance response (SCR). If an emotionally arousing event happens, variations in the SCR are visible as peaks [36,37], which correspond to event-related phasic responses triggered by emotional stimuli.

2.4.5. Arousal and Facial Expression Analysis (FEA)

Another approach for analysing psychophysiological responses is using artificial emotional intelligence. It measures and reports emotions and facial expressions, as well as valence and engagement. Valence is a measure of the negative or positive nature of a person's experience. The observed facial expressions are used to predict the probability that the person is experiencing a certain emotion [38].

Facial expressions can be voluntary and consciously controlled or involuntary and unconscious and can occur spontaneously. A specific region in the brain becomes active if the person is confronted with a stimulus, such as a fearful event. This region not only controls emotional arousal and facial expressions, but also skin conductance, heart rate, and the release of cortisol in the body. Facial expressions can be measured using a coding system for facial landmarks, such as the mouth corners or eyebrows. Using automatic facial-coding processes, human faces are instantaneously detected, the facial expressions coded, and the emotional states recognized [39].

Observable facial expressions for positive emotions include raising the cheeks and smiling while negative emotions are reflected by a lowering of the brow and depression of the lip corners. A neutral expression is when all seven basic emotions (disgust, anger, joy, fear, surprise, sadness, and contempt) are absent [40].

By performing FEA, emotions related to stress, such as anger and disgust, can be detected [41]. Lerner et al. [42] examined the facial responses to stress, such as anger, fear, and disgust, and their association with physiological responses. They found that expressions of fear correlate with both a higher cortisol level and heart rate.

2.5. Possible Effects of Stressful Situations

If a person is triggered by an emotional event, the body responds using various signals. The interaction between the forest environment, machine, and operator influences the driver's psychological and psychophysiological responses, as well as the technical outcomes such as productivity and stand damage.

Many studies clearly showed that working with logging machines on steep slopes tends to decrease working productivity [43,44]. The reasons for the decline in productivity are manifold, including difficulties in material and machine handling, reduced machine mobility, and effects due to the operator's skill level and ability to handle the machinery [44]. However, little is known about the importance of the operator's capability and its effects on working productivity as it is hard to differentiate them from machine-related effects [45]. Furthermore, it is even more challenging to determine the different effects of mental workload on working productivity, although direct correlations between stress and productivity are very likely [23].

Besides productivity, mental stress may also impact working quality as cumulative cognitive fatigue may increase operating errors [46] and cause accidents [47]. In harvesting operations, one way to assess the quality of forest harvesting is to quantify the frequency of tree damage. Damage to the remaining trees can affect tree growth and lower the wood quality due to an increased risk of fungal diseases [48]. The amount and severity of tree

damage depend on many factors, including harvesting system, tree species, season, stand age, and thinning intensity [49]. Bembenek et al. [50] showed that the time of day and accumulated fatigue have a significant influence on the percentage of damaged trees.

Finally, socio-technical work and system design (STS) proposes that human work activities mostly occur as part of a system, which comprises social and technical subsystems. Each individual system, as well as their relationship to one another, must be analysed [51].

3. Participants and Study Sites

This work is designed as a longitudinal exploratory field study. Only forwarder and harvester drivers with at least 1.5 years of work experience between the ages of 18 and 65 who use a traction aid winch as support in a cut-to-length system are selected.

Participants are recruited by contacting forest entrepreneurs who use traction aid winches and work in spruce-dominated stands. These stands are selected to minimize the effects of tree composition on productivity and damage to the remaining trees [23]. Forest owners and companies are contacted about suitable drivers and study sites. In the follow-up, the operators are asked if they are willing to participate.

To better compare the stand density after logging and extraction between the study sites and drivers, the protocol is limited to thinning operations due to the presence of remaining trees to detect possible damage in spruce-dominated stands. Each study site should have a slope gradient ranging from flat (0%–25%) to medium (25%–50%) to steep terrain (>50%). State-of-the-art machinery, particularly harvesters with a tiltable cabin and forwarders with a capacity of 8 to 19 tons, are included in the study. Due to the exploratory nature of this protocol, which focuses on identifying patterns and relationships, no a priori sample size calculation will be conducted.

4. Materials and Equipment

To examine the environmental, machine-related, psychological, psychophysiological, and technical parameters, the following data will be collected, i.e., accelerometer and inclination data, species composition, basic soil parameters, work tasks, sleep quality, arousal, strain, quality of life, mental stress and recovery, heart rate variability, eye fixation duration, cortisol level, electrodermal activity, and facial expression.

4.1. Forest Environment

Key environmental stressors, such as sudden movements of the machine, are recorded using three-dimensional accelerometers and inclination sensors placed inside the cabin next to the driver's seat (Figure 2). Accelerometer data are captured at a frequency of 512 Hz with a Shimmer3 EXG Unit (Shimmer Research TM, Dublin, Ireland), which is reprogrammed using ConsensysBasic software (v.1.6.0, Shimmer). Inclination data is captured using a Dewesoft DS-Gyro1 sensor (DEWESOFT GmbH, Kumberg, Austria).

To record the steepness of the terrain, the Althen NSS1-IP sensor (ALTHEN BV Sensors & Controls, Rijswijk, The Netherlands) is mounted on the chassis of the forest machines (Figure 3). For forwarders with a fixed cabin, only the sensor in the driver's cabin is necessary. Because of the low driving speed of the machines of less than 10 km per hour in this terrain, a lower logging frequency of 10 Hz is used for the inclination measurements. Because of the fully sealed, movable cabin of the machines, it is not easily possible to ensure a wired connection between sensors inside and outside the cabin in a short time. Thus, the data gathered from inside the cabin are recorded using a Dewesoft Krypton datalogger (DEWESOFT GmbH, Kumberg, Austria). The inclination measurements of the chassis are logged by a Graphtec GL-220 datalogger (Graphtec Corporation, Yokohama, Japan). The GNSS-derived time is used to ensure temporal synchrony between the data sets stored

with different dataloggers. The inclination sensors measure the slope in the direction of movement and the lateral inclination.



Figure 2. Positioning of the three-dimensional accelerometer and inclination sensors under the driver's seat.



Figure 3. Inclination sensor in a case mounted on the chassis of a forwarder with a tiltable cabin.

Before the working day, the species composition and basic soil parameters, such as humus layer, soil type, and soil skeleton, are recorded.

4.2. Machine-Related Parameters and Technical Outcomes

Video data is gathered to identify the tasks performed by the drivers. A camera is mounted on the roof of the cabin in the direction of sight of the driver to record the working day. The gathered video material is synchronized with the data from the inclination sensors and divided based on the specific task (Table 1) using the TimeStudies application (version 1.03).

Table 1. Tasks performed by harvester and forwarder operators obtained from video recordings.

Task	Forwarder	Harvester
A	Driving forwards	Boom movement
B	Driving backwards	Felling a tree
C	Loading logs	Processing
D	Manipulation of logs on platform	Manipulation of branches
E	Manipulation of logs, limbs, and stumps	Log manipulation
F	Unload logs	Manipulation of logs
G	Handling the winch	Driving forwards
H	-	Driving backwards

The volume of felled trees is calculated using the diameter measurements of the harvester for each cut. Additionally, the diameter at breast height and travelling distance are sprayed on selected trees in advance of the working day, which are recorded by the camera. For the calculation of the volume transported by the forwarder, the number of logs and a representative diameter of the logs are recorded for each load.

Stand damage is documented after the workday ended and are recorded separately for the different machinery. The location, length, and width of the removed bark on the remaining trees are recorded. The total number of trees, the distance of the damaged tree to the tracks, and the diameter are recorded to calculate the percentage of damaged trees in the thinned stand (Figure 4).

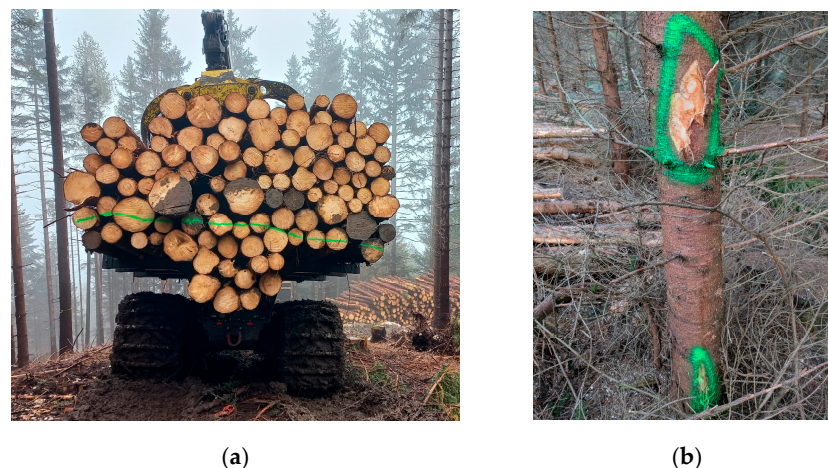


Figure 4. (a) To calculate the transported volume by the forwarder, the number of logs and their diameter are recorded. (b) To measure the stand damage, the location, length, and width of the removed bark are recorded. The green color is used to distinguish between damage caused by the harvester and damage caused by the forwarder.

4.3. Psychological Parameters

All the questionnaires and interviews performed in this study are administered in German, the native language of the Austrian harvester and forwarder driver participants. The questionnaires used are provided in Supplementary Materials.

4.3.1. Sleep, Arousal and Mental Strain

At the beginning of a working day before the driver starts working, they answer Sleep Quality Scale (SQS), Feeling Scale (FS), and Felt Arousal Scale (FAS) questionnaires to assess their sleep quality and currently experienced joy and arousal, as well as the Beanspruchungs-Mess-Skalen (BMS II Version A) to assess the consequences of previously experienced strain. The SQS is a single-item scale that records the overall sleep quality over the last seven days, with scores ranging from 0 (“Terrible”) to 10 (“Excellent”) [52]. The

FS assesses the pleasure of the participant and is a bipolar single-item scale, with scores ranging from −5 (“very bad”) to 0 (“neutral”) to 5 (“very good”) [53]. The FAS is also a single-item scale that assesses the level of activation, with scores ranging from 1 (‘low arousal’) to 6 (‘high arousal’) [54]. The BMS II measures strain in four dimensions (mental fatigue, monotony, mental satiation, and stress) and includes 40 items to which participants respond with ‘agree’ or ‘do not agree’. Two versions are used, with one given before the shift starts, and the other at the end. The total score will be calculated as the difference between the two questionnaires [55]. At the end of the working day, the FS and BMS II (Version B) are given again.

4.3.2. Quality of Life, Mental Stress, and Recovery

To identify any potential confounders and to minimize interruptions, a set of questionnaires are filled out by each participant during the lunch break. This battery includes the short-form health survey (SF-12), which is used to obtain demographic (sex, age, height, and weight), work-related, and quality of life data; the Organizational Fitness test (OrgFit) to assess work-related stress; and the Recovery-Stress Questionnaire for Work (RESTQ-Work) to assess stress and recovery at work. The reliability of the OrgFit was confirmed by analysing a representative sample of employed Austrians [56], and validation of the SF-12 was established by a normative German sample [57].

The work-specific questions include “How many coworkers are in your company?” and “Do you change between harvester and/or forwarder?”. The SF-12 assesses health-related quality of life within two dimensions: physical and mental health, whose scores are combined to give a total score [58]. The OrgFit assesses mental stress and psychosocial risks at work in four dimensions and includes 21 items, which are scored from 0 (“never”) to 6 (“always”) [56]. The RESTQ-Work assesses recovery and stress to determine the effects of high demands using 27 items, whose scores range from 0 (“never”) to 5 (“very often”) [59]. The OrgFit can be used in combination with the RESTQ-Work to assess the mental stress and psychosocial risks in the workplace and to develop measures to reduce the existing stress [60].

4.3.3. Interview

Qualitative interviews—in contrast to quantitative measurements—enable the clarification of different meanings, are open to new, unexpected information about a topic, and can collect data for the different meanings [61]. To explore how a working day was experienced by the participants, a qualitative one-on-one interview is conducted at the end of the day, which lasts for about 2 min. It consists of the following three questions: (1) “What was your most positive experience today?” (2) “What was your biggest challenge?” (3) “Based on your experience, how would you rate the assignment today?” The interview is documented using an audio recorder (Roland R-07, Roland Europe Group Limited Germany, Rüsselsheim, Germany).

4.4. Psychophysiological Parameters

To minimize the interruption to the drivers’ workday, the psychophysiological parameters are assessed over a period of one hour at the beginning and end of a working day.

All the data are simultaneously recorded and analysed using the iMotions biometric research platform, version 10.1.39374.7 (iMotions A/S, Copenhagen, Denmark), which runs on a laptop (Microsoft Surface Laptop Pro) placed inside the cabin behind the driver’s seat (Figure 5).



Figure 5. Equipment used to record and synchronize data, which is placed and secured behind the driver's seat.

The researchers must maintain a safety distance of 90 m from the harvesters and 20 m from forwarder machines. Still, it should be ensured that all the devices are properly connected, and all the signals are recorded. Therefore, a video transmitter/receiver system (Cosmo C1, Hollyland Technology Co., Ltd., Shenzhen, China) with a field monitor (Feelworld LUT7, Ilsede, Germany) is used.

4.4.1. Heart Rate Variability

The participants are equipped with a wearable device that measures their heart rate. It is affixed around the chest according to the manufacturer's recommendations. The Polar H10 device (Polar Electro, Kempele, Finland) is more suitable than electrocardiography and has an acceptable reliability [62,63]. It has a sampling rate of 1000 Hz and is connected via Bluetooth to the laptop.

4.4.2. Eye Fixation Duration

Both stress and the ability to concentrate are investigated by measuring the average fixation duration using Pupil Invisible eye-tracking glasses (Pupil Labs GmbH, Berlin, Germany). These head-mounted eye trackers provide gaze predictions, which are robust to headset slippage and environmental factors, such as outdoor lighting conditions, and do not need to be calibrated [64]. The glasses are directly integrated into iMotions via a portable access point (Netgear Austria GmbH, Vienna, Austria), which can maintain a stable wireless Internet connection in the field.

4.4.3. Cortisol Level

To determine the drivers' cortisol levels, hair samples from the right side of the back of their head are collected at midday. A one centimetre length of a hair is sufficient for analysing the stress responses that occurred over the last month [33]. However, this physiological measure can be combined with the psychological outcome of the OrgFit questionnaire, which records work-related stress over the last four weeks (see Section 4.3.2.). This allows for deeper insights into the psychophysiology of the driver.

4.4.4. Electrodermal Activity

Current psychophysiological stress is examined by recording EDA data at a frequency of 128 Hz using the Shimmer3 GSR+ unit (Shimmer Research TM, Dublin, Ireland). Specifically, SC data is recorded by applying an amplitude threshold of 0.005 μ S to detect SCRs. The associated bipolar gel electrodes are placed on the instep of the left foot (Figure 6) since there is evidence that plantar sites are linked to emotional sweating [36]. This position is as

responsive as fingers, which are usually used, and helps to reduce movement artifacts [65]. This EDA device alone or a combination of FEA and EDA has been demonstrated to be suitable for detecting emotional arousal in real time [66]. This sensor is connected to the laptop via Bluetooth.



Figure 6. To record EDA data, the sensor is placed on the left foot and the associated electrodes are placed on the instep.

4.4.5. Facial Expressions

To analyse the psychophysiological responses of the drivers and their emotions related to stress, video data of the participant's facial expressions are captured at a frequency of 50 Hz and a standard resolution of 640×480 using a Logitech C930e webcam (Logitech, Lausanne, Switzerland), as suggested by iMotions. The camera is clipped onto a mounting rod above the board computer of the machine, focusing on the face of the driver during data collection (Figure 7). It is connected via cable (USB) to the laptop. Video-based FEA in real time allows for the evaluation of valence. It is calculated on a scale ranging from -100 to 100 using iMotions' built-in artificial emotional intelligence: AFFDEX (version 5.1; Affectiva, Boston, MA, USA).



(a)



(b)

Figure 7. (a) To record eye fixation duration, eye-tracking glasses and the associated smartphone are hung on the rearview mirror. A field monitor is used to ensure that all the devices are properly connected and all the signals are recorded. It is mounted beside the board computer. (b) The camera for recording the driver's facial expressions is clipped onto a mounting rod above the board computer of the machine and faces the driver.

We assume that the drivers would be highly concentrated during work and therefore would show more subtle facial expressions. Thus, the AFFDEX threshold for detection is lowered to ten. All the other parameters are measured using the default settings.

5. Detailed Procedure

We examine the interrelationship between the forest environment (acceleration, slope gradient, and inclination of cabin), the machine-related parameters (tasks performed), and the operator and their effects on psychological parameters (sleep, arousal, mental strain, quality of life, mental stress, and recovery), psychophysiological responses (HRV, eye fixation duration, cortisol level, EDA, and emotions), and technical outcomes (productivity and stand damage) using the measurement schedule and data processing methods described below. These data will be analysed in the future.

5.1. Measurement Schedule and Outcomes

At the very beginning, the participants are informed about the study aims, the procedure, and their rights before they are asked to sign a declaration of consent. Then, the different measurements are conducted throughout a regular work shift. Stand-related parameters (species composition and soil properties) are recorded the day before or after the shift to avoid disrupting harvesting operations. Environmental and machine-related data are logged continuously throughout the day (T1–T3). Psychological assessments are conducted before work (T1), which takes around 10 min for each participant. During this time, all the devices are installed on the machine. At midday (T2), hair samples are taken and another questionnaire is administered, which takes around 15 min. At the end of the shift (T3), the third questionnaire is administered, which also lasts for around 10 min. During this time, the measurement devices are removed from the machine. Psychophysiological measures are recorded at T1, after finishing the psychological assessment, and at T3, with eight hours between time point and recorded over a one-hour period. Within this hour, all the different tasks are recorded. Shortly before the driver enters the cabin and starts to work, the sensors are activated and the recording started. Additionally, at the end of the working day (T3), a one-on-one interview is conducted, which lasts around 2 min. The technical outcomes are recorded throughout the shift (T1–T3) or the day after (Table 2).

Table 2. The measured parameters and time points: (T1) beginning of the day, (T2) midday, and (T3) end of the day.

Category	Parameter	T1	T2	T3	Device/Tool
Forest environment	Acceleration	x	x	x	Shimmer3 EXG Unit
	Slope gradient ¹	x	x	x	Althen NSS1-IP
	Inclination of cabin ²	x	x	x	Dewesoft DS-Gyro1
Machine-related	Tasks performed	x	x	x	GoPro
Psychological responses	Questionnaires	x			SQS
		x			FS-A
		x			FAS
		x			BMS II-A
				x	FS-B
				x	BMS II-B
			x		SF-12
			x		OrgFit
			x		RESTQ-Work

Table 2. *Cont.*

Category	Parameter	T1	T2	T3	Device/Tool
	Interview			x	Roland R-07
Psychophysiological responses	HRV	x		x	Polar H10
	Eye fixation duration	x		x	Pupil Invisible
	Cortisol level		x		Hair sample
	EDA	x		x	Shimmer3 GSR+ unit
	Facial expressions ³	x		x	AFFDEX
Technical outcomes	Productivity	x	x	x	GoPro
	Stand damage			x	Measuring tape

The x indicates the timepoint at which the parameter is measured. ¹ Recorded using a Dewesoft Krypton datalogger (DEWESOFT GmbH, Kumberg, Austria). ² Logged by a Graphtec GL-220 datalogger (Graphtec Corporation, Yokohama, Japan). ³ Recorded using a Logitech C930e webcam (Logitech, Lausanne, Switzerland).

The following primary outcomes will be investigated: slope gradient, inclination of the cabin, tasks performed, consequences of previously experienced strain (BMS II), work-related mental stress (OrgFit), eye fixation duration, HRV, productivity, and stand damage rate. The exploratory/secondary outcome parameters were acceleration, sleep quality (SQS), joy (FS), arousal (FAS), recovery and stress (RESTQ-Work), how a working day was experienced (interview), hair cortisol level, EDA, and facial expressions.

5.2. Data Processing

The total scores obtained using the questionnaires will be calculated according to the guidelines of their manuals. To determine the sleep quality (SQS), joy (FS), arousal (FAS), consequences of previously experienced strain (BMS II), quality of life (SF-12), work-related stress (OrgFit), as well as stress and recovery at work (RESTQ-Work), the obtained scores will be compared to the reference value from the norm samples. Additional thresholds and limit values are provided in Table 3.

The recorded data from the interviews will be, after transcription, qualitatively analysed using Quirkos (Quirkos Limited, Edinburgh, Scotland) to gain a better understanding of the drivers' experience during a working day. Additionally, the total scores from the OrgFit questionnaire, which records mental stress and psychosocial risks at work over the last month, will be correlated with the amount of cortisol in the hair samples.

To identify and explain stress-related work situations, within-person changes in the psychophysiological measurements will be compared. This will be performed by analyzing differences in the event-related responses, for example, by comparing low-demand working tasks, such as driving on flat terrain, with possible stress-related work situations. Therefore, there is no need to perform baseline readings since we do not intend to describe brain-body functionality.

Heart rate variability, eye fixation duration, electrodermal activity, and facial expressions will be analysed using the iMotions biometric research platform and a high-performance computer. SCR peaks can be calculated from the raw EDA signals, which can be decomposed into SCR components. EDA peaks can be identified as the region where the amplitude exceeds the predefined threshold. Facial expressions can be calculated as the probability that an emotion was detected. Eye-tracking data can be processed as the eye fixation duration in milliseconds. In addition, a 3 × 3 grid will be laid over the whole environmental scene of the video data recorded by the eye-tracking glasses. To gain more detailed insights into individual information for the interpretation of stressful work situations, automated AOI tracking will be performed using iMotions' built-in Automated AOI module. An object of interest (for example, the broom or the board computer)

will be targeted, and the built-in algorithm can be used to automatically detect the object throughout the whole recording.

Table 3. Reference and threshold values for psychological and psychophysiological parameters used in the protocol.

Parameter	Reference (SD)/Threshold Value
BMS II-A [55]:	
Mental fatigue	38
Monotony	39
Mental satiation	38
Stress	38
BMS II-B [55]:	
Mental fatigue	40
Monotony	41
Mental satiation	40
Stress	45
SF-12 [58]:	
PCS	49.6 (8.7)
MCS	52.3 (8.0)
OrgFit [60]:	
Work tasks and activities	2.66 (0.93)
Social and organizational climate	2.4 (1.01)
Working environment	1.54 (1.02)
Work processes and work organization	2.05 (0.98)
RESTQ-Work [59]:	
Recovery	3.4 (1.01)
Stress	1.85 (1.3)
HRV [67]:	
16–19 years	70.1 ms
20–29 years	51.9 ms
30–39 years	37.7 ms
40–49 years	29.9 ms
50–59 years	24.1 ms
60–69 years	20.7 ms
Fixation duration [27]	>150 ms
Hair cortisol level [68]	182–520 pg/mg ¹

¹ Hair cortisol concentrations were obtained from 3 cm long hair samples from stressed individuals and not the 1 cm length suggested in this study's protocol.

After data export, the psychophysiological measures, which are provided in milliseconds, will be synchronized via a timestamp with the environmental and machine-related data, which are provided in seconds. The different sample sizes and temporal and spatial resolutions and delimitations will necessitate dividing the analysis into different resolutions. Given the multimodal nature of the dataset, a hierarchical analysis strategy will be applied. Analyses of the primary parameters will focus on a set of core parameters that directly test the hypotheses. Additional secondary parameters will be treated as exploratory outcomes.

6. Discussion and Conclusions

This protocol aims to provide an innovative and holistic understanding of the psychophysiological interrelationship between the working conditions and stress of harvester and forwarder drivers in Austria to test the following hypotheses: (1) the higher the mental stress, mental strain, and psychophysiological arousal, the greater the damage to the remaining stand; (2) the ability to concentrate decreases throughout a workday and depends on the difficulty of the work; (3) the higher the mental stress, mental strain, and psychophysiological arousal, the lower the productivity; and (4) the mental stress, mental strain, and psychophysiological arousal are higher in forwarder drivers compared to harvester drivers.

Next, we will discuss how the selected methods complement each other in examining drivers' mental stress, mental strain, and psychophysiological arousal and the interrelationship between the forest environment, machine-related factors, and technical outcomes. By combining environmental and machine-related parameters with psychological and psychophysiological data, this protocol enables the identification and interpretation of stressful work situations. The primary outcome variables include slope gradient, inclination of the cabin, tasks performed, mental stress, mental strain, eye fixation duration, heart rate variability, productivity, and stand damage rate, whereas acceleration, sleep quality, joy, arousal, recovery, how the working day was experienced, hair cortisol level, electrodermal activity, and emotions are treated as exploratory outcomes. This integrated approach provides a deeper understanding of how environmental conditions, machine-related parameters, and human responses interact and differ between harvester and forwarder drivers.

Previous studies have shown that mental workload increases with slope gradient [4]. Interviews and HRV measurements can be used for these assessments [23]. While this study was performed under controlled settings, our protocol can be conducted under real-life conditions and over a longer measurement period. High hair cortisol levels are linked to greater stress at work [34], but these levels were measured retrospectively. We not only propose integrating objective physiological measures (the amount of cortisol in hair) and its correlation with subjectively experienced mental stress (assessed using the OrgFit questionnaire), but also the currently experienced psychophysiological stress (measured through HRV, EDA, and FEA), which represents a novelty in this research field.

Stress can be identified through lowered HRV [24,25]. The slope gradient and other environmental or external factors can affect subjective well-being [17]. High EDA and emotions are also related to stress [66]. Lerner et al. [42] studied two emotions related to stress and measured cortisol levels and heart rate and found that anger should be examined as a situation-specific response. The present protocol intends to analyse seven emotions while performing certain tasks to determine event-related psychophysiological responses. The time of day and fatigue can influence tree damage and operating errors [50]. Therefore, we suggest conducting measurements twice a day to allow for a comparison between the beginning and end of a working day.

The ability to concentrate can be assessed through psychophysiological parameters such as fixation duration, which reflects attention and mental effort [26,27]. Work-related difficulties, for example slippery soil or steep terrain, can reduce concentration and impair work quality [43,44]. While these studies measured the influence of the environment on productivity, we intend to also examine the impact of mental stress, mental strain, and psychophysiological arousal of harvester and forwarder drivers on productivity. Since little is known about operator effects [45], it is possible that increasing mental fatigue decreases productivity. Moreover, soil properties indirectly influence the operator [21].

Finally, because of the increasing usage of fully mechanized harvesting systems in Austria, we aim to investigate the psychophysiological response of the operator while handling the winch since it can be physically demanding to connect the cable of the

winch with the machine. By comparing the psychophysiological arousal in different work situations and between harvester and forwarder drivers, we intend to gather a comprehensive picture of this working environment. However, instead of separating the aforementioned parameters or analysing a smaller set of parameters, this work combines all these aspects into a longitudinal exploratory study by simultaneously measuring all these parameters.

The anticipated challenges related to the Bluetooth range include the possibility that connections could drop when the drivers leave the cabin (e.g., for equipment maintenance) and could fail to auto-reconnect if absent for more than 20 min, interrupting the data collection. This must be considered when conducting measurements. Limited driver availability could also reduce the sample size. In addition, the latest eye-tracking glasses, which can record pupil dilation, were unavailable during protocol development. We strongly recommend using eye-tracking glasses in future research, as the pupil size changes in response to increased levels of mental effort or arousal [69]. Furthermore, most devices are designed for use under perfect laboratory conditions. When used in the field under diverse environmental conditions, ranging from freezing to high temperatures and vibrations from the machine, there is a possibility that the devices could shut down unexpectedly. Safety regulations, such as risk zones extending to up to 90 m, only allow for remote measurement methods. Finally, combining the large amount of acquired data could be challenging because of the different units and temporal and spatial resolutions: the psychophysiological data (in milliseconds) will have to be processed in a different unit than the forest environmental and machine-related parameters (in seconds). In addition, productivity data will have to be calculated as time-based performance per hour and stand damage will have to be calculated per day for forwarders or based on area for harvesters. The time lag between the reaction to stressful work situations and their effects on machine operation should also be considered.

The key strengths of this work are the successful adaptations of sensitive devices for challenging field conditions, enabling near-continuous data capture and the extensive data that can be gathered. The one-hour measurement intervals offer detailed insights into the drivers' psychophysiological states throughout the workday and while performing specific tasks.

To conclude, this study protocol provides an innovative multimodal exploratory approach that combines several research fields. By integrating environmental, machine-related, psychological, psychophysiological, and technical data, it allows for a comprehensive understanding of the interrelationship between the forest environment, operator, and machine in real harvesting operations. This protocol provides a framework for improving the occupational health of forest workers, increasing their productivity, and reducing possible damage to remaining trees.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/f16111693/s1>, Sleep Quality Scale (SQS) Questionnaire; Feeling Scale (FS) Questionnaire; Felt Arousal Scale (FAS) Questionnaire; Beanspruchungs-Mess-Skalen Form A (BMS-A) Questionnaire; Beanspruchungs-Mess-Skalen Form B (BMS-B) Questionnaire; short-form health survey (SF-12) Questionnaire; Organizational Fitness Test (OrgFit) Questionnaire; Recovery Stress (RESTQ-Work) Questionnaire.

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References

1. Lackner, C.; Schreck, M.; Walli, A.-M. *Austrian Forest Report 2023*; Federal Ministry of Agriculture, Forestry, Region, and Water Management: Vienna, Austria, 2023.
2. Holzfeind, T.; Visser, R.; Chung, W.; Holzleitner, F.; Erber, G. Development and Benefits of Winch-Assist Harvesting. *Curr. For. Rep.* **2020**, *6*, 201–209. [CrossRef]
3. Jodłowski, K.; Kalinowski, M. Current Possibilities of Mechanized Logging in Mountain Areas. *For. Res. Pap.* **2018**, *79*, 365–375. [CrossRef]
4. Szewczyk, G.; Spinelli, R.; Magagnotti, N.; Tylek, P.; Sowa, J.; Rudy, P.; Gaj-Gielarowicz, D. The Mental Workload of Harvester Operators Working in Steep Terrain Conditions. *Silva Fenn.* **2020**, *54*, 10355. [CrossRef]
5. Holzfeind, T.; Stampfer, K.; Holzleitner, F. Productivity, Setup Time and Costs of a Winch-Assisted Forwarder. *J. For. Res.* **2018**, *23*, 196–203. [CrossRef]
6. Kühmaier, M.; Stampfer, K. Development of a Multi-Criteria Decision Support Tool for Energy Wood Supply Management. *Croat. J. For. Eng.* **2012**, *33*, 181–198.
7. Cavalli, R.; Amishev, D. Steep Terrain Forest Operations—Challenges, Technology Development, Current Implementation, and Future Opportunities. *Int. J. For. Eng.* **2019**, *30*, 175–181. [CrossRef]
8. Hittenbeck, J. Limitations of highly mechanized timber harvesting in slopes. *AFZ-DerWald* **2011**, *66*, 30–33.
9. Visser, R.; Stampfer, K. Expanding Ground-Based Harvesting onto Steep Terrain: A Review. *Croat. J. For. Eng.* **2015**, *36*, 321–331.
10. Garland, J.; Belart, F.; Crawford, R.; Chung, W.; Cushing, T.; Fitzgerald, S.; Green, P.; Kincl, L.; Leshchinsky, B.; Morrisette, B.; et al. Safety in Steep Slope Logging Operations. *J. Agromed.* **2019**, *24*, 138–145. [CrossRef] [PubMed]
11. Nemestóthy, N. Erhebung der Holzerntekapazitäten und Waldpflegekapazitäten der in Österreich tätigen Forstbetriebe bzw. forstlichen Dienstleistungsunternehmen und Entwicklung Einer Datenbank als Informationssystem für Waldbewirtschafter 2022. Available online: https://www.forstholzpapier.at/images/BEILAGE_E_Top6_NEMESTOTHY_Abschlussbericht_Holzerntekapazit%C3%A4t_korr2022-07.pdf (accessed on 4 August 2025).
12. Grollnigg, M.; Bauer, H. Holzeinschlagsmeldung 2022. Bundesministerium für Land- und Forstwirtschaft, Regionen und Wasserwirtschaft. 2023. Available online: <https://www.bmluk.gv.at/dam/jcr:31024149-0f7a-45d8-bfb4-add65900c0cd/Brosch%C3%BCre%20HEM.pdf> (accessed on 4 August 2025).
13. ÖNORM EN ISO 10075-1:2017-01; Ergonomische Grundlagen Bezüglich Psychischer Arbeitsbelastung—Teil 1: Allgemeines Und Begriffe (Ergonomic Principles Related to Mental Workload—Part 1: General Terms and Definitions). Austrian Standards International: Vienna, Austria, 2018.
14. Gaillard, A.W.K. Comparing the Concepts of Mental Load and Stress. *Ergonomics* **1993**, *36*, 991–1005. [CrossRef]

15. Hacker, W.; Richter, P. *Psychische Fehlbeanspruchung. Psychische Ermüdung, Monotonie, Sättigung und Streß*; Zweite, veränderte und ergänzte Auflage; Springer: Berlin/Heidelberg, Germany, 1984; Volume 2, ISBN 978-3-642-87990-6.
16. Matti, N.; Mauczok, C.; Specht, M.B. Müdigkeit, Fatigue und Erschöpfung: Alles das Gleiche oder Ausprägungen eines Kontinuums?—Ein Diskussionsanstoß. *Somnologie* **2022**, *26*, 187–198. [\[CrossRef\]](#)
17. Das, K.V.; Jones-Harrell, C.; Fan, Y.; Ramaswami, A.; Orlove, B.; Botchwey, N. Understanding Subjective Well-Being: Perspectives from Psychology and Public Health. *Public Health Rev.* **2020**, *41*, 25. [\[CrossRef\]](#)
18. Diener, E. *The Science of Well-Being: The Collected Works of Ed Diener*, 1st ed.; Springer Science & Business Media: Berlin/Heidelberg, Germany, 2009; Volume 37.
19. Lee, D.H.; Kim, Y.J.; Choi, C.H.; Chung, S.O.; Nam, Y.S.; So, J.H. Evaluation of Operator Visibility in Three Different Cabins Type Far-East Combine Harvesters. *Int. J. Agric. Biol. Eng.* **2016**, *9*, 33–44.
20. Naskrent, B.; Grzywiński, W.; Polowy, K.; Tomczak, A.; Jelonek, T. Eye-Tracking in Assessment of the Mental Workload of Harvester Operators. *Int. J. Environ. Res. Public Health* **2022**, *19*, 5241. [\[CrossRef\]](#)
21. Cambi, M.; Certini, G.; Neri, F.; Marchi, E. The Impact of Heavy Traffic on Forest Soils: A Review. *For. Ecol. Manag.* **2015**, *338*, 124–138. [\[CrossRef\]](#)
22. Cacioppo, J.T.; Tassinary, L.G.; Berntson, G.G. Psychophysiological Science. In *Handbook of Psychophysiology*; Cambridge University Press: Cambridge, UK, 2000; pp. 123–138, ISBN 62634X.
23. Spinelli, R.; Magagnotti, N.; Labelle, E.R. The Effect of New Silvicultural Trends on the Mental Workload of Harvester Operators. *Croat. J. For. Eng.* **2020**, *41*, 175–190. [\[CrossRef\]](#)
24. Singh, N.; Moneghetti, K.J.; Christle, J.W.; Hadley, D.; Plews, D.; Froelicher, V. Heart Rate Variability: An Old Metric with New Meaning in the Era of Using mHealth Technologies for Health and Exercise Training Guidance. Part One: Physiology and Methods. *Arrhythmia Electrophysiol. Rev.* **2018**, *7*, 193. [\[CrossRef\]](#)
25. iMotions. *Electrocardiography (ECG): The Complete Pocket Guide 2020*; iMotions: Copenhagen, Denmark, 2020.
26. iMotions. *Eye Tracking: The Complete Pocket Guide 2017*; iMotions: Copenhagen, Denmark, 2017.
27. Galley, N.; Betz, D.; Biniossek, C. Fixation Durations—Why Are They so Highly Variable? In *Das Ende von Rational Choice? Zur Leistungsfähigkeit der Rational-Choice-Theorie*; SSOAR: Mannheim, Germany, 2015; Volume 3, pp. 1–26.
28. De Rivecourt, M.; Kuperus, M.N.; Post, W.J.; Mulder, L.J.M. Cardiovascular and Eye Activity Measures as Indices for Momentary Changes in Mental Effort during Simulated Flight. *Ergonomics* **2008**, *51*, 1295–1319. [\[CrossRef\]](#)
29. Liu, J.-C.; Li, K.-A.; Yeh, S.-L.; Chien, S.-Y. Assessing Perceptual Load and Cognitive Load by Fixation-Related Information of Eye Movements. *Sensors* **2022**, *22*, 1187. [\[CrossRef\]](#) [\[PubMed\]](#)
30. Szewczyk, G.; Spinelli, R.; Magagnotti, N.; Mitka, B.; Tylek, P.; Kulak, D.; Adamski, K. Perception of the Harvester Operator's Working Environment in Windthrow Stands. *Forests* **2021**, *12*, 168. [\[CrossRef\]](#)
31. Kamgang, V.W.; Murkwe, M.; Wankeu-Nya, M. Biological Effects of Cortisol. In *Cortisol—Between Physiology and Pathology*; IntechOpen: London, UK, 2023.
32. Veltman, J.A.; Gaillard, A.W.K. Indices of Mental Workload in a Complex Task Environment. *Neuropsychobiology* **1993**, *28*, 72–75. [\[CrossRef\]](#)
33. Greff, M.J.E.; Levine, J.M.; Abuzgaia, A.M.; Elzagallaai, A.A.; Rieder, M.J.; van Uum, S.H.M. Hair Cortisol Analysis: An Update on Methodological Considerations and Clinical Applications. *Clin. Biochem.* **2019**, *63*, 1–9. [\[CrossRef\]](#)
34. Van der Meij, L.; Gubbels, N.; Schaveling, J.; Almela, M.; van Vugt, M. Hair Cortisol and Work Stress: Importance of Workload and Stress Model (JDCA or ERI). *Psychoneuroendocrinology* **2018**, *89*, 78–85. [\[CrossRef\]](#)
35. Mundy-Castle, A.C.; McKiever, B.L. The Psychophysiological Significance of the Galvanic Skin Response. *J. Exp. Psychol.* **1953**, *46*, 15–24. [\[CrossRef\]](#) [\[PubMed\]](#)
36. Boucsein, W. *Electrodermal Activity*; Springer: Berlin/Heidelberg, Germany, 2012; pp. 1–3, 27, 31, ISBN 978-1-4614-1125-3.
37. iMotions. *Galvanic Skin Response: The Complete Pocket Guide 2017*; iMotions: Copenhagen, Denmark, 2017.
38. Affectiva Emotion AI 101: All About Emotion Detection and Affectiva's Emotion Metrics. Available online: <https://blog.affectiva.com/emotion-ai-101-all-about-emotion-detection-and-affectivas-emotion-metrics> (accessed on 4 August 2025).
39. iMotions. *Facial Expression Analysis: The Complete Pocket Guide*; iMotions: Copenhagen, Denmark, 2017.
40. Bishay, M.; Preston, K.; Straffuss, M.; Page, G.; Turcot, J.; Mavadati, M. AFFDEX 2.0: A Real-Time Facial Expression Analysis Toolkit. *arXiv* **2022**, arXiv:2202.12059. [\[CrossRef\]](#)
41. Gao, H.; Yuce, A.; Thiran, J.-P. Detecting Emotional Stress from Facial Expressions for Driving Safety. In Proceedings of the 2014 IEEE International Conference on Image Processing (ICIP), Paris, France, 27–30 October 2014; IEEE: New York, NY, USA, 2014; pp. 5961–5965.

42. Lerner, J.S.; Dahl, R.E.; Hariri, A.R.; Taylor, S.E. Facial Expressions of Emotion Reveal Neuroendocrine and Cardiovascular Stress Responses. *Biol. Psychiatry* **2007**, *61*, 253–260. [\[CrossRef\]](#)
43. Bolding, M.C.; Lanford, B.L. Productivity of a Ponsse Ergo Harvester Working on Steep Terrain. In Proceedings of the 25th Annual Council on Forest Engineering Meeting, Auburn, AL, USA, 16–20 June 2002.
44. Petitmermet, J.; Sessions, J.; Bailey, J.; Zamora-Cristales, R. Cost and Productivity of Tethered Cut-to-Length Systems in a Dry-Forest Fuel-Reduction Treatment: A Case Study. *For. Sci.* **2019**, *65*, 581–592. [\[CrossRef\]](#)
45. Gullberg, T. Evaluating Operator-Machine Interactions in Comparative Time Studies. *J. For. Eng.* **1995**, *7*, 51–61. [\[CrossRef\]](#)
46. Gallis, C. Increasing Productivity and Controlling of Work Fatigue in Forest Operations by Using Prescribed Active Pauses: A Selective Review. *Croat. J. For. Eng. J. Theory Appl. For. Eng.* **2013**, *34*, 103–112.
47. Axelsson, S.-Å.; Pontén, B. New Ergonomic Problems in Mechanized Logging Operations. *Int. J. Ind. Ergon.* **1990**, *5*, 267–273. [\[CrossRef\]](#)
48. Bajrakatri, A.; Pimenta, R.; Pinto, T.; Miranda, I.; Knapic, S.; Nunes, L.; Pereira, H. Stem Quality of *Quercus Cerris* Trees from Kosovo for the Sawmilling Industry. *Drewno. Pr. Naukowe. Doniesienia. Komun.* **2018**, *61*, 57–69. [\[CrossRef\]](#)
49. Kühmaier, M.; Kanzian, C.; Holzfeind, T. *Weiterentwicklung Eines Benchmark-Modells zur Prognose und Bewertung von Bestandesschäden bei der Holzernte im Seilgelände—Demonstration am Beispiel des Forstbetriebs Franz Mayr-Melnhof-Saurau und Der Forstverwaltung Quellenschutz*; Project report; Institut für Forsttechnik, Department für Wald- und Bodenwissenschaften, Universität für Bodenkultur: Vienna, Austria, 2021; p. 54.
50. Bembenek, M.; Tsioras, P.A.; Karaszewski, Z.; Zawieja, B.; Bakinowska, E.; Mederski, P.S. Effect of Day or Night and Cumulative Shift Time on the Frequency of Tree Damage during CTL Harvesting in Various Stand Conditions. *Forests* **2020**, *11*, 743. [\[CrossRef\]](#)
51. Ulich, E. Unternehmensgestaltung im Spannungsfeld von Stabilität und Wandel. In *Neue Erfahrungen und Erkenntnisse*; Vdf Hochschulverlag AG: Zollikon, Switzerland, 2016; Volume 2.
52. Snyder, E.; Cai, B.; DeMuro, C.; Morrison, M.F.; Ball, W. A New Singel-Item Sleep Quality Scale: Results of Psychometric Evaluation in Patients with Chronic Insomnia and Depression. *J. Clin. Sleep. Med.* **2018**, *14*, 1849–1857. [\[CrossRef\]](#)
53. Hardy, C.J.; Rejeski, W.J. Not What, But How One Feels: The Measurement of Affect During Exercise. *J. Sport Exerc. Psychol.* **1989**, *11*, 304–317. [\[CrossRef\]](#)
54. Svebak, S.; Murgatroyd, S. Metamotivational Dominance: A Multimethod Validation of Reversal Theory Constructs. *J. Personal. Social Psychol.* **1985**, *48*, 107–116. [\[CrossRef\]](#)
55. Debitz, U.; Plath, H.-E.; Richter, P. *Beanspruchungs-Mess-Skalen. Manual* 2016; Hogrefe: Göttingen, Germany, 2016.
56. Jiménez, P.; Dunkl, A.; Bramberger OrgFit—Organisational Fitness. Instrument Zur Erfassung Der Arbeitsbezogenen Belastung 2014. Available online: <https://orgfit.eu> (accessed on 6 May 2025).
57. Drixler, K.; Morfeld, M.; Glaesmer, H.; Brähler, E.; Wirtz, M.A. Validierung der Messung gesundheitsbezogener Lebensqualität mittels des Short-Form-Health-Survey-12 (SF-12 Version 2.0) in einer deutschen Normstichprobe. *Z. Psychosom. Med. Psychother.* **2020**, *66*, 272–286. [\[CrossRef\]](#)
58. Gandek, B.; Ware, J.E.; Aaronson, N.K.; Apolone, G.; Bjorner, J.B.; Brazier, J.E.; Bullinger, M.; Kaasa, S.; Lepke, A.; Prieto, L.; et al. Cross-Validation of Item Selection and Scoring for the SF-12 Health Survey in Nine Countries: Results from the IQOLA Project. *J. Clin. Epidemiol.* **1998**, *51*, 1171–1178. [\[CrossRef\]](#) [\[PubMed\]](#)
59. Jiménez, P.; Kallus, W. *The Recovery-Stress Questionnaire/Erholungs-Belastungsfragebögen. User Manual* 2016; Pearson Frankfurt am Main: Frankfurt, Germany, 2016.
60. Jiménez, P.; Bregenzer, A.; Höfer, M.; Hubich-Schmon, C. *OrgFit. Ein Instrument zur Erfassung der arbeitsbezogenen Belastungen. Manual* 2022; OrgFit: Netherlands, MO, USA, 2022.
61. Hohl, J. Das qualitative Interview. *Z. Gesundheitswissenschaften* **2000**, *8*, 142–148. [\[CrossRef\]](#)
62. Gilgen-Ammann, R.; Schweizer, T.; Wyss, T. RR Interval Signal Quality of a Heart Rate Monitor and an ECG Holter at Rest and during Exercise. *Eur. J. Appl. Physiol.* **2019**, *119*, 1525–1532. [\[CrossRef\]](#)
63. Speer, K.E.; Semple, S.; Naumovski, N.; McKune, A.J. Measuring Heart Rate Variability Using Commercially Available Devices in Healthy Children: A Validity and Reliability Study. *Eur. J. Investig. Health Psychol. Educ.* **2020**, *10*, 390–404. [\[CrossRef\]](#)
64. Tonsen, M.; Baumann, C.K.; Dierkes, K. A High-Level Description and Performance Evaluation of Pupil Invisible. *arXiv* **2020**, arXiv:2009.00508. [\[CrossRef\]](#)
65. van Dooren, M.; de Vries, J.J.G.; Janssen, J.H. Emotional Sweating across the Body: Comparing 16 Different Skin Conductance Measurement Locations. *Physiol. Behav.* **2012**, *106*, 298–304. [\[CrossRef\]](#)
66. Fortune, E.; Yusuf, Y.; Blocker, R. Measuring Arousal and Emotion in Healthcare Employees Using Novel Devices. In Proceedings of the 2020 IEEE 20th International Conference on BioInformatics and BioEngineering (BIBE), Cincinnati, OH, USA, 26–28 October 2020; pp. 835–838.
67. Van Den Berg, M.E.; Rijnbeek, P.R.; Niemeijer, M.N.; Hofman, A.; Van Herpen, G.; Bots, M.L.; Hillege, H.; Swenne, C.A.; Eijgelsheim, M.; Stricker, B.H.; et al. Normal Values of Corrected Heart-Rate Variability in 10-Second Electrocardiograms for All Ages. *Front. Physiol.* **2018**, *9*, 424. [\[CrossRef\]](#)

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68. Gonzalez, D.; Jacobsen, D.; Ibar, C.; Pavan, C.; Monti, J.; Fernandez Machulsky, N.; Balbi, A.; Fritzler, A.; Jamardo, J.; Repetto, E.M.; et al. Hair Cortisol Measurement by an Automated Method. *Sci. Rep.* **2019**, *9*, 8213. [[CrossRef](#)] [[PubMed](#)]
 69. Mathôt, S. Pupillometry: Psychology, Physiology, and Function. *J. Cogn.* **2018**, *1*, 16. [[CrossRef](#)] [[PubMed](#)]

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