Brief Report

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

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Abstract: (1) Background: The proportion of fully mechanized harvesting systems in Austria is constantly increasing especially because of the technological development of the machines, which allows them to drive on increasingly steep terrain. This leads to additional challenges and potential hazards for the operators, which may also cause higher stress levels. The purpose of this study is to develop and debate a new set of methodologies for determining time and space resolved psychophysiology data to analyze stressful and non-stressful work situations for harvester and forwarder operators; (2) Methods: we suggest a study protocol to analyze a) tasks performed by the driver, b) environmental factors, like slope gradient, c) the psychophysiological response of experts during these tasks, and d) evaluate the worker´s subjective stress and fatigue before and after a harvest operation. (3) Results: Within this manuscript we present a study protocol based on quantitative and qualitative methods, like time and space resolved psychophysiology, questionnaires, qualitative interviews, as well as video and sensor-based analysis of environmental and machine data. The first results from real measurements of a forwarder driver are presented; (4) Conclusions: This multimodal research protocol serves to explore the relationship between stress, fatigue, and performed tasks. Through our quantitative and qualitative methodology, researchers can improve the health and safety of forest workers at work, improve their productivity and reduce damage to remaining trees.

Keywords: emotion recognition; eye tracking; forwarder; galvanic skin response; harvester; heart rate variability; psychophysiology; strain; stress; traction aid winches

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1. Introduction

Fully mechanized harvesting systems are gaining importance in Austrian forests. The proportion of timber extracted by forwarders increased from 33% in 2012 to 39% of the harvested timber in 2022. The high quantity of new harvesters and forwards owned by forest entrepreneurs - not older than 5 years - document the economic expectations in this technology in the next years [1,2]. Socioeconomic reasons can be seen as a driver of the trend to higher shares of fully mechanized harvesting systems in Austria. Comparatively high labor costs and a stagnating price development for timber products increase the financial pressure in timber harvesting, resulting in a higher popularity of fully mechanized systems. Technological developments lead to more efficient harvesting operations with potentially low rates of damaged trees in the remaining stand [3,4]. Bogie tracks and traction-aid winches, originally designed to decrease the negative impacts of the heavy machinery on the soil, now lead to applications on steep terrain with slope gradients up to 60% and

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higher - dependent on soil properties and configuration of applied machines [5,6]. In contrast to manual motor harvesting systems, fully mechanized systems tend to decrease the number of serious injuries to people as they are well protected by the safety structure of the cabin [4,7,8]. Working with harvesters and forwarders poses many stressors and hazards for the drivers, especially while working in mountainous areas. The main driver's challenges range from difficulties maneuvering the machines on uneven terrain to variable soil conditions, which influences the working progress [9]. Other stressors concern the human´s physiological and psychological states of conducting such a work, respectively what amount of stress the drivers are exposed to while operating such heavy machines under partly extreme environmental conditions.

This leads to the research field of mental workload, which is described as the adjustment between environmental requirements and individual abilities [10]. The impact of the working environment on the operator's mental workload can be - among others - assessed using the eye tracking method. By analyzing eye activity, it was shown, that the driver´s mental workload increased with steepness of the terrain. Szewczyk et al. [11] suggested that the harvester driver was very aware of using the machine at its limits of capacity while driving through the steepest segments.

The discipline of psychophysiology is based on two assumptions, that 1) human emotion, thought, perception, and action are physical phenomena embedded in human consciousness, and 2) the responses of the brain and body hold information that can explain human processes through an appropriate experimental design [12]. To gain a deep understanding of the driver´s psychophysiology and the environment, analyzing a set of parameters is useful. Not only physiological measurements, such as eye activity but also others, such as heart rate (HR) and galvanic skin response (GSR), and psychological measures using questionnaires can be used to determine mental workload, stress, fatigue, and well-being.

Another approach is using an artificial emotional intelligence (Emotion AI), which 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 have either a negative or positive effect on the probability of an emotion [13]. Thus, by combining all these factors into one analysis, a deep understanding of the psychophysiological interrelationship between working conditions and stress of forwarder and harvester drivers can be gained.

Therefore, the purpose of the present work is to develop methods to identify and examine stressful work situations for both harvester and forwarder drivers using a multimodal approach (Figure 1). Using this study protocol we want to answer following hypotheses: 1) the greater the mental workload, stress and/or fatigue, the greater the damage to the remaining stand; 2) the ability to concentrate decreases over the course of a workday, depending on the difficulty of the work; and 3) the higher the fatigue, the less timber is harvested.

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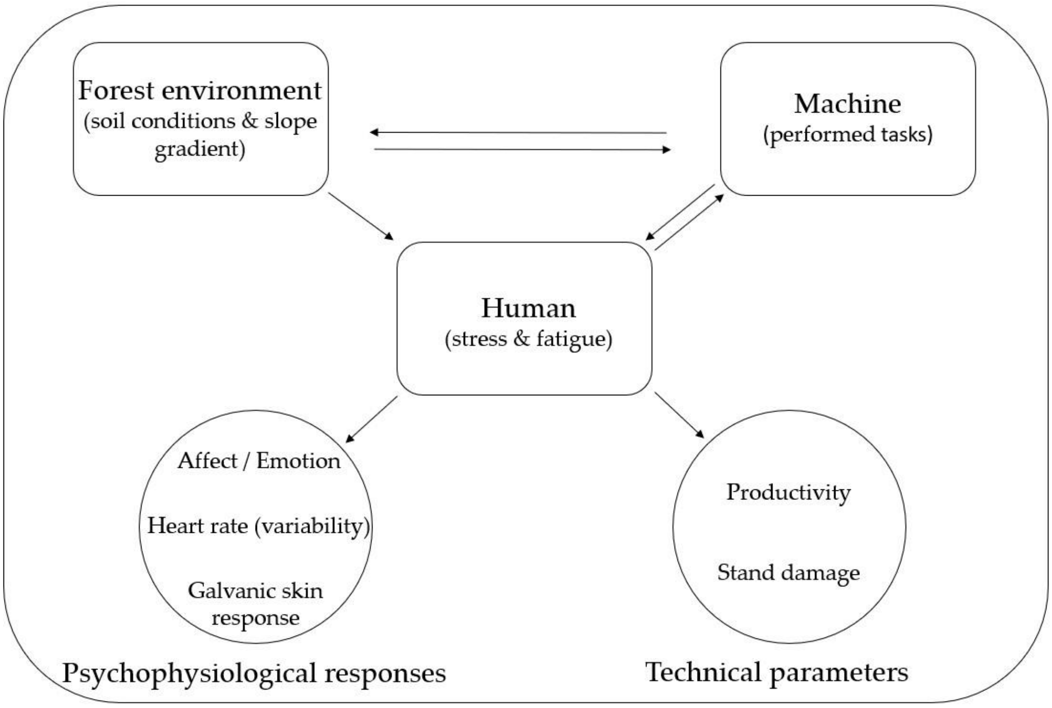

Figure 1. Interrelationship between human - forest environment, human - machine, and forest environment - machine, and the according outcome parameters.

2. Materials and Methods

Based on our hypothesis, relevant parameters that influence human stress, fatigue, and the ability to concentrate are determined. Therefore, factors such as slope gradient, soil conditions, performed tasks, and stand properties should be discussed. In a further step, methods for estimating the effect on the drivers need to be considered, including potential effects of stress and fatigue on the stand and working productivity.

2.1. Psychological Outcome Parameters

To correctly interpret results and to derive explanations for treatment and diagnosis recommendations, it is important to adequately define interrelated but distinct outcome parameters.

The concept of mental workload is complex, comprising of several aspects, such as effort, feelings, strategy, practice, and individual differences [10]. Strain is defined as all detectable external influences that affect people psychologically [14]. But it is important to note, that stress and strain are distinct outcome variables, originating from different concepts.

According to Gaillard [15], stress is characterized by disruption and over reactivity, thus if someone has fear of losing control or feels threatened. But both, stress and mental workload refer to the connection of environmental needs and resources that are available meeting those requirements. Reactions of stress can also occur if one experiences monotony, thus mental workload being too low.

Another term, which needs to be adequately defined is fatigue. If exhaustion intensifies, resulting in a chronic loss of energy, which is characterized by cognitive, emotional, and physical symptoms, fatigue is the consequence [16]. Finally, subjective well-being is affected by external and internal factors. Determinants, such as personal goals, activities, emotions, or needs, have an effect on the subjective well-being [17].

2.2. Parameters Influencing Psychological Parameters

Many factors are influencing the working environment of harvester and forwarder operators. The applied machine including the model, age, technical condition of the harvester or forwarder is of importance. Cabin rotation and cabin tilt was found to improve the visibility during harvesting

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operation and therefore improve productivity and decrease workload [18,19]. Also, the choice of bogie tracks and the use of traction aid winches is relevant for the well-being of the driver. The duration and schedule of work shifts, weather and visibility conditions affect the rate at which fatigue develops [19]. Szewczyk et al. [20] showed that workload for harvester operators increased when working in conditions with higher slope gradients. Holzfeind et al. [21] confirmed that steep terrain is more challenging for the driver and leads to lower productivity during tethered logging operations.

The most stressful situation for harvester and forwarder operators is to potentially tip over or a rollover. For machines working with traction aid winches, this could occur from a failure of tethered lines or due to traversal slope or compromised positions. Traction aid winches lead to a decreasing number of accidents in New Zealand, but new hazards and stressful situations can occur because working on even steeper slopes is possible [7]. Soil properties are influencing the trafficability and stability of the machinery on steep slopes, consequently having an impact on the operator. Rutting depth and wheel slippage is dependent on various soil properties such as soil texture, moisture, organic matter content and additionally slope of the terrain [22]. Schönauer et al. [23] compared terramechanical test procedures and found that the easy to measure penetration depth of soils lead to accurate predictions of the rutting depth.

2.3. Assessment of Psychophysiological Parameters

To gather a comprehensive picture of the psychophysiology of the driver, a set of qualitative interviews, quantitative questionnaires, as well as objective physiological measures, using a multimodal research protocol, can be useful.

The impact of a complex working environment on the mental workload and work performance has already been examined. Spinelli et al. [24] conducted interviews and heart rate variability of harvester operators and found that subjective performance contributed to mental workload, which increased when passing from pure conifer into mixed stands.

The beating heart generates electrical activity, that can be measured by electrodes using electrocardiography (ECG). A heartbeat can be split into three waves, and one part, the R wave, represents the spike of it. Thus, heart rate reflects the frequency of all these parts. However, heart rate variability (HRV) is defined as a physiological change in the interval between those R waves, respectively the RR interval. Under conditions of emotional stress, the heartbeat shows a lower variability between the R intervals, thus the HRV is decreasing. However, there are other devices to monitor HRV including the pulse oximeter, which is put on the finger or an ear, or wearables, such as wrist bands and watches. Most of these devices depend on the optical technique called photoplethysmography (PPG). But ECG electrodes, which are used in chest straps, are more accurate then PPG sensors [25,26].

During a simulated flight, HRV data was collected using a chest strap, fixation duration using eye activity measures, as well as a rating scale to assess mental stress under different tasks. With increasing task load, the heart rate increased, respectively the HRV decreased, as well as the fixation duration [27].

There are screen-based eye tracking devices and mobile eye tracking glasses to record eye movements and activity. Most used metrics for measurement of visual interest and attention are fixations and saccades. Fixations are, if a person looks at a specific object, and saccades are defined as the eye movements between them [28].

Assessment of mental workload in real-life settings was performed by analyzing saccade duration obtained from mobile eye-trackers, which had to be calibrated prior use. When comparing logging categories, Naskrent et al. [19] described higher levels of workload for harvester operators in clearcuts compared to working in windbreaks or thinning operations. However, eye fixation duration increases with increasing mental workload, which was determined using a device which tracks the dominant eye of the participant [29]. Finally, Szewczyk et al. [30] distinguished the recorded video data into four different work activities and analyzed both, saccades and fixation duration to determine the driver´s mental workload [30]. So, if a person is triggered by an emotional event, the body responses with various signals.

Cortisol is a hormone, which has an important role in the human body, since it is responsible for physiological changes, while responding to stress. Those changes are required when dealing with upcoming stressful situations [31]. Veltman and Gaillard [32] evaluated HRV determined by experienced pilots and cortisol using saliva samples as an indicator for mental workload, and found that the HRV was reduced while flying in more complex scenarios, whereas the cortisol level slightly increased. However, the average cortisol exposure over the last one or two months can also be analyzed using one or two centimeters of a hair sample collected from the head [33]. van der Meij et al. [34] suggested that a high hair cortisol concentration relates to a high mental workload as well as self-reported stress at work.

Emotional arousal, such as stress, can be measured by the change in skin conductance, which is generally defined as galvanic skin response (GSR). Within the skin are sweat glands and whenever they are triggered by an emotional stimulus, they release moisture. The changing of negative and positive ions in the sweat, results in current flowing more easily, and these changes can be measured in the skin conductance. Thus, being exposed to a fearful stimulus, induces emotional arousal, which causes increased sweat secretion, respectively a higher GSR. Analysing this data is performed by calculating GSR peaks, respectively the event-related response of the skin conductance [35].

GSR is an important measure in the field of psychophysiology [36]. While performing difficult tasks, it was found that the recorded GSR values increased with increasing cognitive load [37]. Additionally, cognitive processes such as attention while performing different tasks, can be measured using functional near-infrared spectroscopy (fNIRS) sensors positioned on the head [38].

2.4. Facial Expression Analysis (FEA)

Facial expressions can be voluntary and consciously controlled or involuntary and unconscious, occurring spontaneously. There is a specific region in the brain being active, if a person is confronted with a stimulus, such as a fearful event. This region not only controls emotional arousal respectively facial expression but also skin conductance, heart rate, and the release of cortisol into the body -these parameters will be explained later. Measuring facial expressions can be performed using a coding system for facial landmarks, such as mouth corners or eyebrows. With the use of automatic facial coding processes, faces can be instantaneously detected, facial expressions coded, and emotional states recognized [39].

Observable facial expressions, such as raising the cheek and smiling account for positive emotions. While negative emotions are considered active, when the participant is lowering the brow and depressing the lip corner. Whereas 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 of car drivers can be detected [41]. Lerner et al. [42] examined the facial responses to stress, respectively anger, fear, and disgust and their association with physiological responses. They found that expressions of fear correlate to both a higher cortisol level and heart rate.

2.5. Possible Effects of Stressful Situations

Many studies clearly show that working on steep slopes with logging machines tend 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 operator effects [44]. However, little is known about the importance and magnitude of operator effects as it is hard to differentiate them from machine 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 seem to be very likely [24].

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

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species, season of the year, stand age, thinning intensity [49], one of which is the operator. Bembenek et al. [50] already showed that the part of day combined with accumulated fatigue has a significant influence on the percentage of damaged trees.

3. Results and Discussion

In this section we describe our specific study protocol - before showing first data - obtained out of the different methods mentioned in the previous section. With this guideline, we and other researchers can analyze the complex interplay of various factors, such as: environmental parameters (like slope gradient) interacting with machine data (tasks performed by the driver) and vis versa; psychophysiological responses (emotions, galvanic skin response, and heart rate variability) of harvester and forwarder drivers to these environmental and machine parameters while performing certain tasks; as well as subjectively experienced determinants (stress, recovery, activation, strain, fatigue and wellbeing) and technical parameters (productivity and stand damage) resulting from the usage of fully mechanized machines and the impact of the forest environment. Furthermore, we present the first data gained by using this multimodal approach.

3.1. Participants and Study Sites

The present work was designed as a longitudinal experimental field study. It aimed to assess stressful work situations, in the context of forest damage, of harvester and forwarder operators working with and without traction-aid winches in terrain of varying steepness. Data acquisition started in spring of 2022 and will last over three years. Male forwarder and harvester drivers, with at least 1.5 years of work experience, between the ages of 18-65, who use a traction aid winch as support in a cut-to-length system, which is typically used in highly mechanized harvesting systems in Austria, were selected.

The participants were recruited by looking for forest entrepreneurs with traction aid winches, working at spruce dominated stands. These stands were selected to minimize the effects of tree composition on productivity and stand damage of the remaining trees [24]. Only thinning operations were used to have comparable conditions for the comparison of stand density after logging and extraction. Forest owners and companies were called and asked for suitable drivers and sites. In a follow-up the drivers were asked if they were willing to participate. Because the usage of a specific questionnaire, which will be explained in section 3.4.1, requires a sample size of twelve, six forwarder and six harvester drivers with two to three repeated measures per participant shall be observed during the study to obtain a sample size of 36.

For better comparison between the study sites and the drivers, the study was limited to thinning operations due to remaining trees to detect damage in spruce-dominated stands. Each study site should have a slope gradient, ranging from flat (0-25%) to medium (25-50%), and steep terrain (>50%). Within the study, state of the art-machinery in the Austria context is used, therefore we focused on modern harvesters with a tiltable cabin and forwarder with a capacity of 12 to 19 tons. Hence, an applicability of the results on a wide range of machinery used in Austria will be possible.

Participants voluntarily in the study and signed a declaration of consent. The ethics committee of the Paracelsus Medical University Salzburg, Austria, approved the study and voted it positively (WS 2223-0025-0072).

3.2. Measurement Schedule

Different measures were carried out during a regular work shift. Psychological quantitative and qualitative data (Questionnaires and an Interview) was assessed before the participant started working (T1), around midday (T2), as well as at the end of the working day (T3). To determine the subjectively experienced strain throughout the day, a questionnaire will be filled out at the beginning and end of the working day. To evaluate whether the stress level increases and/or concentration decreases over the course of a working day, physiological measures will be taken at the beginning and end of a work shift, with eight hours between. As suggested in another study [19], the period of

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eight hours is based on the duration of a regular working day. These measurements were performed over a timespan of one hour each. Within this hour it will be assured that the recording of all the different tasks is covered. To determine possible influencing factors and effects on the stand without interfering with the harvesting operation species composition, soil parameters and damage to remaining tress, were taken one day before the shift or the next day after. Throughout the working day inclination and acceleration data was recorded on a datalogger (Table 1). Additionally, video data was gathered to identify tasks performed by the drivers (Table 2) and assess productivity.

Table 1. Different parameters taken at timepoint T1) beginning of day, T2) midday, and T3) end of day. Abbreviations: SQS – Sleep Quality Scale, FS – Feeling Scale (A and B), FAS – Felt Arousal Scale, BMS II – Beanspruchungs-Mess-Skalen (Form A and B), SF-12 – short form health survey, OrgFit – organizational fitness test, RESTQ-Work – recovery stress questionnaire, HRV – heart rate variability, GSR – galvanic skin response.

Measures	T1	T2	T3
Psychological:			
SQS	x		
FS-A	x		
FS-B			x
FAS	x		
BMS II-A	x		
BMS II-B			x
Interview			x
SF-12		x	
OrgFit		x	
RESTQ-Work		x	
Physiological:			
HRV	x		x
GSR	x		x
Emotions	x		x
Fixation duration	x		x
Environmental:			
Tasks	x	x	x
Productivity	x	x	x
Inclination	x	x	x
Acceleration	x	x	x

Table 2. Tasks performed by harvester and forwarder operator with data obtained by video recordings.

Tasks	Forwarder	Harvester
A	driving forwards	driving forwards
B	driving backwards	driving backwards
C	loading the logs	felling
D	manipulation of logs on platform	delimbing
E	manipulation of logs, limbs and stumps	manipulation of limbs and stumps
F	unload logs	manipulation of logs
G	handling the winch	handling the winch
H	-	brush cutting

3.3. Environmental Parameters

Since stress is often caused by environmental influences, the most relevant stressors to the drivers were collected: To assess sudden movements of the machines, three dimensional accelerometry sensors were placed inside the cabin next to the driver's seat. Accelerometry data were captured with a frequency of 512 Hz with a Shimmer3 EXG Unit, which was a reprogrammed Shimmer3 EXG Unit using ConsensysBasic software (v.1.6.0, Shimmer).

To assess both the current steepness of the terrain and the inclination of the cabin, inclination sensors were mounted inside the cabin (Dewesoft DS-Gyro1) and on the chassis of the forest machines (Althen NSS1-IP). For forwarders with fixed cabin only the sensor in the driver's cabin was necessary. Because of the low driving speed of the machines in the terrain of less than 10 km per hour, a lower logging frequency of 10 Hz was chosen for 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 recorded inside the cabin was recorded using a Dewesoft Krypton datalogger. The inclination measurement of the chassis was logged by a Graphtec datalogger GL-220. The GNSS-derived time was used to ensure temporal synchrony between the data sets stored with different dataloggers.

3.4. Psychological Parameters

All standardized questionnaires mentioned in this section, as well as the interview, are in the German language, since harvester and forwarder drivers working in Austria will be examined, with their native language being German. Furthermore, the questionnaires were tested for reliability by analyzing a representative sample of employed Austrians [51] and validated by analyzing a normative German sample [52].

3.4.1. Subjective Stress and Strain

At the beginning of a working day, before the driver would start working, the sleep quality and currently experienced joy and arousal were recorded by the "Sleep Quality Scale" (SQS), the "Feeling Scale" (FS), the "Felt Arousal Scale" (FAS), as well as the consequences of previously experienced stress and strain using the "Beanspruchungs-Mess-Skalen" (BMS II-Version A). The SQS is a single item scale that records the overall sleep quality over the last seven days ranging from 0 = "Terrible" to 10 = "Excellent" [53]. The FS records the pleasure of a participant and is a bipolar single-item scale ranging from -5 = "very bad" over 0 = "neutral" to 5 = "very good" [54]. The FAS, which is also a single item scale to assess the level of activation, ranging from 1 = ´low arousal´ to 6 = ´high arousal´ [55]. The BMS measures stress and strain in four dimensions, including 40 items to which participants 'agree' or ´do not agree´. There are two different versions – one must be recorded before the shift starts and the other at the end. The difference between both is taken as a measure to obtain a total score [56]. In our case these two groups were each six harvester and forwarder drivers. At the end of a working day, the FS and BMS II (Version B) were again recorded.

3.4.2. Quality of Life, Mental Stress, Recovery and Strain

For assessment of potential confounders and to minimize interruptions, sets of questionnaires were filled out once per participant during the lunch break. This battery records demographic data (sex, age, height, weight), work-related questions, quality of life with the short-form health survey (SF-12), work-related stress by the Organizational-Fitness test (OrgFit), as well as strain and recovery at work using the Recovery-Stress Questionnaire for Work (RESTQ-Work).

Work-specific questions were, for example, "How many coworkers are in your company?" or "Do you change between harvester and / or forwarder?". The SF-12 records health-related quality of life within two dimensions consisting of physical and mental health, obtained by a total score [57]. The OrgFit assesses mental stress and psychosocial risks at work in four dimensions, including 21 items ranging from 0 = "never" to "6 = "always" [51]. The RESTQ-Work records recovery and stress to determine effects of high demands using 27 items, which range from 0 = "never" to 5 = "very often" [58]. To assess psychological stress and strain on the workplace, the OrgFit in combination with the RESTQ-Work, can be used to develop measures to reduce existing stress that can lead to misuse [59].

3.4.3. Interview

A qualitative interview - in contrast to a quantitative - enables the clarification of different meanings, is open to new, unexpected information about a topic, and it collects data on different levels of meaning [60]. Since we want to explore, how a working day was experienced in the eye of the participant, we conducted a qualitative interview at the very end of the day. It covers the following three questions: 1) "What was your most positive experience today?"; 2) "What was your biggest challenge?"; and 3) "Based on your experience, how would you rate the assignment today?".

3.5. Physiological Parameters

To keep the time short, in which we interrupted the drivers during their work, the following parameters were assessed over a timespan of one hour, each at the beginning (after psychological assessment) and end of a working day (before psychological assessment). All data were simultaneously recorded and analyzed using the iMotions biometric research platform version 9.4.0.4 (iMotions A/S, Copenhagen, Denmark).

Since one must keep a safety distance of 90m to the Harvester, respectively 20m to the Forwarder machine, at first, there was no possibility of managing the devices after measurement began. Therefore, to control whether all devices are properly connected and that signals are recorded, a video transmitter / receiver system (Cosmo C1, Hollyland Technology Co., Ltd., Shenzhen, China) with a field monitor (Feelworld LUT7, Ilsede, Germany) was used.

3.5.1. Heart rate variability

To determine mental workload, participants were equipped with a wearable device, which senses heart rate. It was affixed around the chest, as stated by the manufacturer's recommendations. The Polar H10 (Polar Electro, Kempele, Finland) is valid compared to electrocardiography and has acceptable reliability [61,62]. It has a sampling rate of 1000 Hz and was connected via Bluetooth to a laptop (Microsoft Surface Laptop Pro). This computer was put inside the cabin, behind the driver´s seat.

3.5.2. Eye-tracking

To determine time and space resolved physiology, respectively average fixation duration, Pupil Invisible eye tracking glasses were used (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 [63]. The glasses were directly integrated into iMotions via a portable access point (Netgear Austria GmbH, Vienna, Austria) that maintains a stable wireless Internet connection in the field.

3.5.3. Cortisol level

During midday, hair samples from the right side of the back of the head were taken to analyze the amount of cortisol to determine work related stress. One centimeter length of a hair sample was decided to be enough, because 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 3.4.2.). This allows a deep insight into the stress-psychophysiology of the driver.

3.5.4. Galvanic skin response

GSR data were measured at 128 Hz using the Shimmer3 GSR+ unit (Shimmer Research TM, Dublin, Ireland). The according bipolar gel electrodes were put on the instep of the left foot to reduce movement artifacts -this position is as responsive as the finger, which is usually used [64]. This GSR device alone, as well as a combination of FEA and GSR, are valid in detecting emotional arousal in real-time [65]. This sensor was connected to the afore-mentioned laptop via Bluetooth.

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While using Bluetooth devices, it is noteworthy considering the range of connectivity. During test-phasis it was discovered that the connection was lost, as the driver got out of the cabin (to maintain the harvester head or to move the winch). If the driver would not get back to the cabin, thus to the laptop to which the devices are connected, within a time span of 20 minutes, the devices would not reconnect automatically resulting in interrupted data collection. This must be considered when conducting a measurement.

3.5.5. Facial expression

To analyze participants´ facial expression, respectively emotions, video data was captured at 50 Hz and a standard resolution of 640x480 using a Logitech C930e webcam (Logitech, Lausanne, Switzerland), which was suggested by iMotions. The camera was clipped onto a mounting rod above the board computer of the machine, focusing on the face of the driver during data collection. It was connected via cable (USB) to the laptop. Video-based FEA in real time allows the evaluation of valence. It was calculated on a scale ranging from -100 to 100 using iMotions´ built-in artificial emotional intelligence AFFDEX version 5.1 (Affectiva, Boston, MA).

The fNIRS sensor (see section 2.2.) must be placed on the forehead. But we decided to use eye tracking glasses, too much of the respondent's face would be covered to appropriately analyze the facial expressions. Therefore, this sensor was excluded.

3.6. First Results

Using the methods described above, we want to suggest data analysis and provide preliminary data to give a preview of expected results. Statistical analysis will be performed after reaching the desired sample size.

3.6.1. Psychological Parameters – Data Analysis

The total scores from the data obtained using the questionnaires were calculated according to the guidelines of their manuals. To determine the consequences of previously experienced stress and strain, quality of life, work-related stress, as well as strain and recovery at work, the obtained scores were compared to the reference value from the norm samples.

3.6.2. Psychological Parameters – First Data

Respondent´s sleep quality (SQS) was rated as "good". Affective valence after the working shift (FS-B) was higher compared to the beginning of the day (FS-A). However, activation (FAS) in the morning was relatively high. The respondent´s ratings for stress and strain before and after the work (BMS II-A and BMS II-B) did not deviate from the reference values, suggesting wellbeing. Although the values were higher at the end of day, indicating an increase in subjective strain and stress throughout the day. Physical health (PCS) was slightly worse than the norm, whereas mental health (MCS) was even better. This might be due to the challenging complexity of performing such a work. However, the dimensions used to evaluate the impact of performed tasks, as well as the working environment were rated lower compared to the reference, suggesting strain resulting from the tasks and prevailing conditions at the workplace. Whereas the social and organizational climate was good as well as the work organization. Indicating that the respondent works in a pleasant team, with a good division of labor (OrgFit). Finally, recovery was good, and the respondent had a lower stress level compared to the norm. Suggesting sufficient opportunities to recreate, since the accumulation of stress in the work is low (Table 3).

Table 3. Mean scores of the different dimensions calculated for the questionnaires, filled out by one forwarder driver (*n*= 1) and mean reference values obtained from norm samples. Abbreviations: SQS – Sleep Quality Scale, FS (A and B) – Feeling Scale, FAS – Felt Arousal Scale, BMS II– Beanspruchungs-Mess-Skalen (version A and B), SF-12 – short form health survey, OrgFit – organizational fitness test, RESTQ-Work – recovery stress questionnaire, HRV – heart rate variability, GSR – galvanic skin response.

Questionnaire	Score (SD)	Reference (SD)
SQS	8	*NA*
FS-A	2	*NA*
FS-B	3	*NA*
FAS	4	*NA*
BMS II-A:		
Mental strain	37.67	38
Monotony	38.5	39
Mental saturation	37.75	38
Stress	38	38
BMS II-B:		
Mental strain	39.8	40
Monotony	41.33	41
Mental saturation	39.8	40
Stress	45.17	45
SF-12:		
PCS	46.36	49.03 (9.35)
MCS	59.44	52.24 (8.1)
OrgFit:		
Work tasks & activities	0.75 (0.96)	2.66 (0.93)
Social and organizational climate	5.6 (0.55)	2.4 (1.01)
Working environment	1 (1.91)	1.54 (1.02)
Work processes & work organization	2.5 (2.42)	2.05 (0.98
RESTQ-Work:		
Recovery	3.54 (0.93)	3.4 (1.01)
Stress	1.43 (1.62)	1.85 (1.3)

3.6.3. Physiological Parameters – Data Analysis

Heart rate variability, galvanic skin response, fixation duration, and emotions were analyzed using the iMotions biometric research platform. Since we observed that the drivers were highly concentrated during their work, therefore showing more subtle facial expressions, the AFFDEX thresholding for facial expression analysis was lowered to ten. After data-export, the physiological measures were synchronized via a timestamp with the environmental data, including slope gradient and tasks. Then the percentage obtained with the binary GSR data (0 = no peaks, 1 = has peaks) was calculated. If a peak was detected, the other parameters, such as average HRV, slope gradient, as well as percentage of positive, negative, and neutral emotions were calculated for each task. To correlate the HRV with eye tracking data, the average fixation duration in milliseconds (ms) was calculated by using the number of fixations per area of interest (AOI) per second. The AOIs were defined as a 3x3 grid over the whole environmental scene of the driver.

To determine stressful work situations for the harvester and forwarder drivers, the whole recording of one hour was split into the different tasks. It was then analyzed how many galvanic skin response peaks (GSR peaks) occurred, how high or low the HRV was, which emotions (positive, negative, and neutral) were detected, and how steep the terrain was. The slope gradient was recorded by inclination sensors on the harvester and forwarder. To determine the slope in direction of the movement and the lateral inclination, the sensor was mounted on harvesters under the cabin. Due to tiltable cabins of harvesters a second sensor was mounted inside of the cabin to record the inclination and acceleration under the driver's seat. For forwarders with fixed cabin only the sensor in the driver's cabin was necessary. For each sequence of a task, detected in the time and motion study, the mean inclination was calculated to relate stress with tasks. Furthermore, a correlation analyses between the steepness of the terrain or lateral inclination and stress level for distinct time periods were performed. Damage to the remaining stands created by the harvester and working productivity were correlated with the stress level in the morning and in the evening session. Damages caused by the extraction by the forwarder and its working productivity cannot be correlated on an hourly basis due to long travel distances and therefore were correlated daily. Stand parameters like tree species composition, stand density, DBH, tree height, soil parameters and harvesting intensity were also correlated with the stress level per working day.

3.6.4. Physiological Parameters – First Data

In the following, data obtained from a forwarder operator will be explained. The forwarder driver spent most of the time loading the logs (task C), followed by driving backwards (task B), driving forwards (task A), unloading the logs (task F), handling the winch (task G), manipulation on the platform (task D), and at least time manipulating the forest (task E). The most GSR peaks, therefore a high stress level, were recorded while handling the winch (task G), as well as the second lowest HRV. This is mostly likely due to the physical activity of moving through the forest and possible movement artifacts, since the GSR electrodes stuck on the left foot. Another stressful situation was manipulation on the platform (task D), in which the lowest HRV was detected, therefore a high stress level, and no positive emotions were expressed. Since the thresholding for FEA was lowered, the probability for detecting neutral emotions (when all seven basic emotions are absent) is higher, as can be seen in Figure 2. Noteworthy that there were more negative than positive emotions detected.

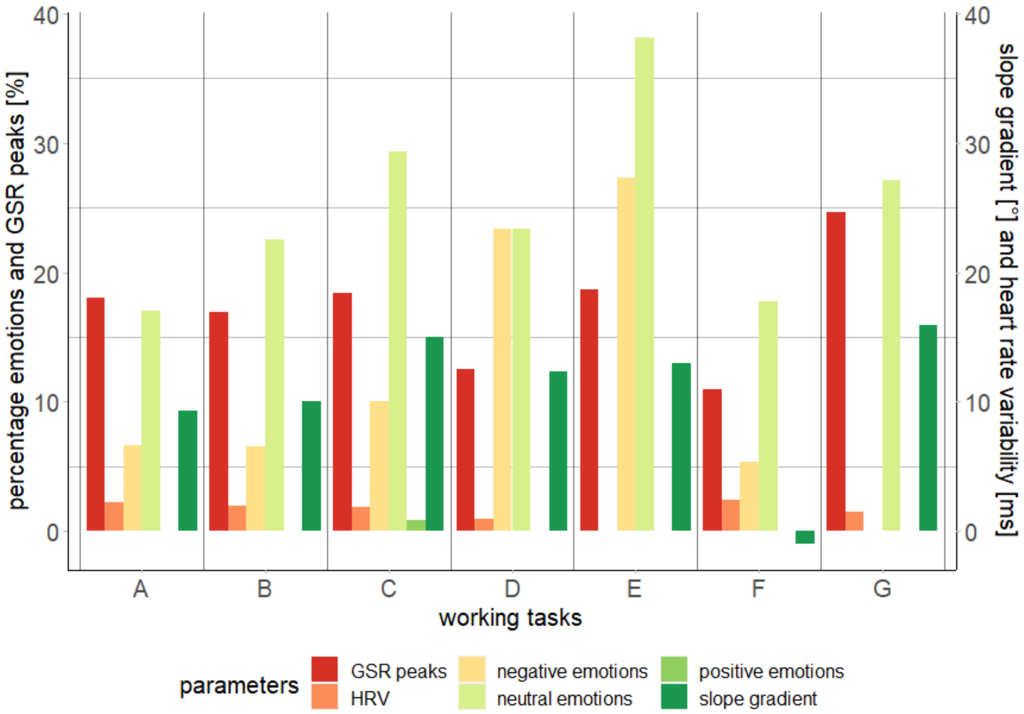

Figure 2. Tasks performed by the operator (in percentage): A) driving forwards, B) driving backwards, C) loading the logs, D) manipulation on platform, E) manipulation of limbs and stumps, F) unload logs, and G) handling the winch. Data was obtained from the time-and-motion study, environmental (slope gradient), and physiological measures (in percentage) like heart rate variability, GSR peaks, positive, negative, and neutral emotions of a forwarder driver examined during the first hour of a regular working shift. .

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To get an even deeper understanding of the mental workload while performing specific tasks, time and space resolved physiology was analyzed. The average fixation duration (in milliseconds) for each of the areas of interest and the according HRV was calculated for each of the seven performed tasks. In the following, data regarding the manipulation on the platform is presented. Fixation duration was highest (830 ms) and HRV was low (0.95 ms), during manipulation on platform, indicating a high mental workload, especially when looking at the top right corner of the grid. The same pattern was observed, while the driver was looking at the bottom (Figure 3).

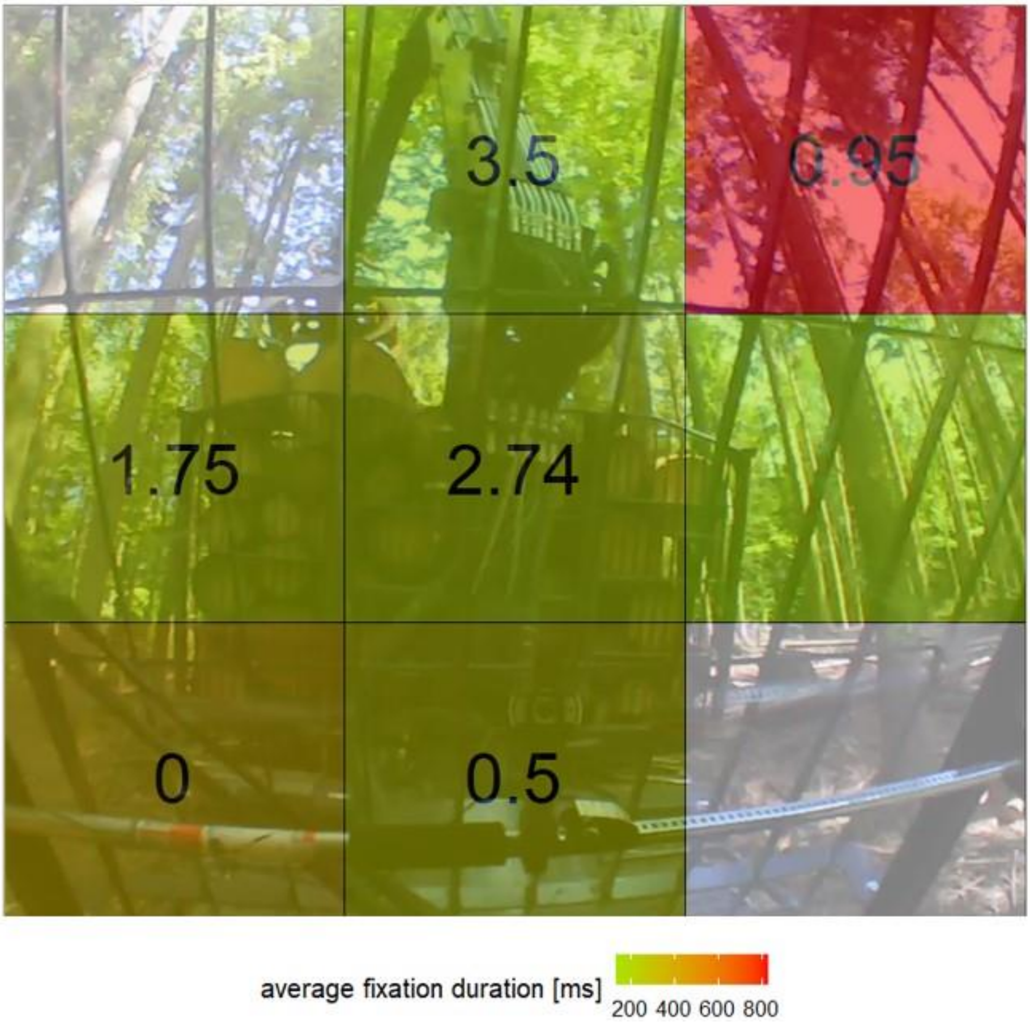

Figure 3. Heart rate variability (represented as numbers) and average fixation duration (represented by the color grading) in the according area of interest calculated as a 3x3 grid with data obtained using eye tracking glasses during the task of manipulation on the platform.

4. Conclusions

Following the guideline of this multimodal research protocol and using the set of suggested parameters enables us and other researchers to obtain an interpretation of the psychophysiology and environment of forwarder and harvester drives.

By using the set of questionnaires, we could evaluate the sleep quality, joy, arousal, as well as stress and strain experienced throughout a workday. Furthermore, quality of life, work-related stress, as well as strain and recovery at work were assessed. Finally, by conducting an interview, additional information about the personal evaluation and assessment of the working day was gathered.

With the use of the prescribed physiological measures, we could determine stressful work situations by assessing galvanic skin response, heart rate variability, emotions, and eye fixation duration. By separating the recordings taken at the beginning and end of a working shift into the tasks performed by the operator, and synchronizing them with the physiological measures, a deeper understanding of the complex work of such experts is provided.

Limitations of this study protocol include that most devices are designed for usage under perfect laboratory conditions. While using them in the field under diverse environmental conditions, ranging from snow to heat and vibrations from the machine, it could be that anytime a device shuts down. Safety regulations such as risk zones - up to 90 m - only allow remote methods during forest operations. Another limitation is the availability of drivers participating in the study, resulting in a reduced sample size.

Supplementary Materials: The following supporting information can be downloaded at the website of this paper posted on Preprints.org. SQS-Questionnaire: Sleep Quality Scale; FS-Questionnaire: Feeling Scale; FAS-Questionnaire: Felt Arousal Scale; BMS-A-Questionnaire: Beanspruchungs-Mess-Skalen (Form A); BMS-B-Questionnaire: Beanspruchungs-Mess-Skalen (Form B); SF-12-Questionnaire: short form health survey; OrgFit-Questionnaire: Organizational fitness test; RESTQ-Work-Questionnaire: recovery stress questionnaire.

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Data Availability Statement: We encourage all authors of articles published in MDPI journals to share their research data. In this section, please provide details regarding where data supporting reported results can be found, including links to publicly archived datasets analyzed or generated during the study. Where no new data were created, or where data is unavailable due to privacy or ethical restrictions, a statement is still required. Suggested Data Availability Statements are available in section "MDPI Research Data Policies" at https://www.mdpi.com/ethics.

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