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MASTER

Validation of a hypovigiliance-management-system for industrial workers

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Validation of a Hypovigilance-Management-System for Industrial Workers

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Preface

After receiving my Bachelor Degree at the department of Mechanical Engineering of the Fontys Hogescholen in Eindhoven, I decided to follow the master program of Human-Technology-Interaction at the University of Technology in Eindhoven. This study broadened my horizon by combining my technical knowledge with issues from the field of the social sciences. It gave me the tools, which I needed to be able to find solutions to problems raised by the introduction of new technologies.

To finish my master's study, I was looking for a challenging graduation assignment in Germany. After a brief search, I came in contact with the Institute for Human Factors and Technology Management of the University of Stuttgart and the Fraunhofer Institute for Industrial Engineering. They offered me the opportunity to prepare, to conduct and to evaluate a very interesting experiment: *the validation of a Hypovigilance-Management-System for Industrial Workers.*

Many people have supported me during my graduation. First of all, I would like to thank Lorenz Hagenmeyer for his amazing input and excellent guidance. He always made time to answers my questions and I have learned very much from him.

Marie-Luise Quesseleit assisted me in the preparation and the execution of the experiments. For this purpose, she had to mixed up her sleep-wake schedule by being present at 4 a.m. every experiment (26 times). She was always on time and she fulfilled her tasks wonderfully and I am very grateful for that.

Furthermore, I would like to thank the entire 863-team. It was fun to be member of this team and I enjoyed every single day at their office.

Paul de Greef was my supervisor at the University of Technology in Eindhoven. I am very grateful for his support and his review.

Finally, I would like to thank my wife (Cornelia van den Hurk), my parents (Huub and Joke van den Hurk) and my family-in-law (Erich and Erika Joos) for their unconditional support during my education. Without them, none of this would have been possible.

Stuttgart, February 24, 2007

Pernel van den Hurk

Summary

Human beings need to sleep. Sleep is not a matter of choice, it is essential and inevitable. The longer someone stays awake, the greater the need to sleep and the more difficult it is to resist falling asleep. Sleep will eventually overpower the strongest intentions and efforts to stay awake (NCSDR/NHTSA 1998). Sleepiness reduces reaction time, impairs the ability to perform attention based activities, diminishes the speed of information processing and affects the quality of decision-making of the hypovigilant[1] individual (ROSPA 2001).

Industrial workers are vulnerable as a result of hypovigilance, because they often are engaged in shift work and they often suffer unsuitable break patterns. These factors could have a negative influence on their accident rate, resulting in personal or economical damage.

In order to prevent such accidents, technical support systems, so-called Hypovigilance-Management-Systems (HVMS(s)), are developed. These systems detect hypovigilance via sensors and according algorithms, warn the individual prior to hazardous situations and, optionally, provide a vigilance-maintaining function to keep the user alert for a certain period of time, usually until he/she can securely end the current task and take a rest. However, a HVMS can improve safety only if the communication between the HVMS and the user, which is established by means of the human-machine-interface (HMI), works properly.

IAT (University of Stuttgart) and Fraunhofer IAO developed a universal HMI for the SENSATION HVMS[2] including both the warning strategy and its technical implementation, i.e., the physical HMI-elements. It is a prototype and its effectiveness has to be validated in practice.

In an experimental setting, it was to be tested if the performance of the industrial worker was affected positively when using the SENSATION HVMS. It was expected that participants using the SENSATION HVMS would produce more units and would make less mistakes than participants without technical assistance. Moreover, it was assumed that participants using a HVMS with random warning signals would also perform better than participants without technical assistance, but at the same time would perform worse than the participants using the SENSATION HVMS.

Therefore, a "factory test" was created, based on a real task of an industrial worker. It consisted of a psycho-motor test and a divided attention test. At the psycho-motor test, metal components for television screens and monitors were manufactured in an

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[1] The term hypovigilance origins from the French language. It consists of the word *vigilance* and the Greek prefix *hypo*. Hypo means diminished. Thus, hypovigilance can be defined as a state of diminished vigilance.

[2] SENSATION refers to the EU co-founded project that develops unobtrusive and wireless HVMSs.

imaginary welding process. It was a simple positioning task, which required a good hand-eye-coordination. Parallely, a divided attention test was carried out, representing a semi-automated production process. Every now and then, the buffer of the production line had to be emptied in order to avoid damages to products, tools or machines. The divided attention test required the ability to selectively concentrate on one or more parameters while ignoring others.

The abilities needed for the psycho-motor and the divided attention test were impaired when the participant got sleepy, leading to a decrease in production speed and to an increased risk of mistakes. The "factory test" was preceded/ended by two test batteries of a standardized neuro-pychological test (in order to measure mental status) and by a subjective sleepiness rating.

24 students (22-31 years old) participated in the experiment and they were divided into three treatment groups. Each participant attended two experimental trials: the *evening test* and the *morning test.* Between both tests, the participants underwent total sleep deprivation in order to simulate the negative effects of working on a night shift schedule. The evening test was conducted from 6 p.m. till 8 p.m. with the goal of reducing learn effects as well as conducting a baseline measurement. The morning test was conducted from 4:30 a.m. till 8 a.m. in order to maximize the effects of the sleep deprivation. Here, the three groups received different treatments: *no warning strategy*, *random warning strategy* and *SENSATION warning strategy.*

The research questions and corresponding hypotheses could not be answered by the experiment. The SENSATION warning group did not perform significantly better than the no warning group. Likewise, the random warning group did not perform better than the no warning group and the SENSATION warning group did not perform significantly better than the random warning group. However, the relatively large spread in variation of the results of the SENSATION warning group compared to the other two groups was striking. Some participants in the SENSATION warning group performed better than the best participants in the no warning group and some performed worse than the worst performing participant in the no warning group. This difference indicates that the SENSATION HVMS is helpful for some persons and disturbing for others. Thus, it could have helped some participants to make accurate decisions when to take a break. However, by its mere presence, it could have also reminded the participants of the two other groups that they were sleepy.

In other fields of application (e.g., the transportation sector) the effectiveness of the SENSATION HVMS is probably larger, because such tasks are more monotonous and less dynamic. Moreover, the physical activation resulting from the psycho-motor test could have (partly) counteracted the effects of sleep deprivation. It might be concluded that the SENSATION HVMS is not suitable for all kinds of tasks.

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Abbreviations

Abbreviation	Description
a.m.	ante meridiem [engl.: before midday]
ANOVA	Analysis of Variance
BAN	Body Area Network
dB	decibel
D-MEQ	German Morningness–Eveningness Questionnaire
e.g.	exempli gratia [engl.: for example]
EEG	Electroencephalography
et al.	et alumni [engl.: and colleagues]
EU	European Union
etc.	et cetera [engl.: and other similar things]
exp.	experiment
GAU	Größter Anzunehmender Unfall [engl.: worst case scenario]
h	hour
$H_{(0)}$	null hypothesis
$H_{(a)}$	alternative hypothesis
H	score of Kruskal-Wallis test
HMI	Human-Machine-Interface
HTI	Human Technology Interaction
HVMS	Hypovigilance Management System
IAO	Institut für Arbeitswirtschaft und Organisation [engl.: Institute for Industrial Engineering]
IAT	Institut für Arbeitswissenschaft und Technologiemanagement [engl.: Institute for Human Factors and Technology Management]
i.e.	id est [engl.: that is]
KSS	Karolinska Sleepiness Scale
LAN	Local Area Network
LED	Light-Emitting Diode
M	mean
max.	maximum
MEQ	Morningness–Eveningness Questionnaire
N	number of participants
n.s.	not significant
p	probability value
P	performance

Abbreviation	Description
PC	Personal Computer
p.m.	post meridiem [engl.: after midday]
PVC	Polyvinyl Chloride
Q	quantity
r	effect size
RH	Relative Humidity
SD	Standard Deviation
SENSATION	Advanced Sensor Development for Attention, Stress, Vigilance & Sleep/Wakefulness Monitoring
SPSS	Statistical Package for the Social Sciences
SSS	Stanford Sleepiness Scale
T	score of Wilcoxon signed-rank test
TAP-M	Tests for Attentional Performance-Mobility
TFT	Thin Film Transistor
TU/e	Technische Universiteit Eindhoven [engl.: Eindhoven University of Technology]
U	score of Mann-Whitney test
U.S.	United States
V	Variable of TAP-M
VHS	Video Home System
VMM	Vigilance Maintaining Mode
wrn.	warning
χ^2	Chi-square

1 Introduction

1.1 Relevance of Research

Today's "24 hour society" causes many people to sacrifice their sleep in favor of other activities, without realizing the negative effects on the ability to perform a wide range of tasks. Sleepiness reduces reaction time, impairs the ability to perform attention based activities, diminishes the speed of information processing and affects the quality of decision-making of the hypovigilant[1] individual (ROSPA 2001).

Statistics about road traffic show that a large number of fatal accidents are caused by fatigue. The American National Highway Traffic Safety Administration estimates that there are 100.000 crashes which are caused by hypovigilant drivers and it results in more than 1.500 fatalities and 71.000 injuries every year in the U.S. (NCSDR/NHTSA 1998). In the same way, hypovigilance more and more becomes a safety issue in the field of manufacturing and process control: with a steadily increasing degree of automation, the amount of monotonous but safety critical control tasks increases. Furthermore, hypovigilance was discovered to be an important factor in some of the worst nuclear accidents, such as Chernobyl and Three-mile Island (Mitler et al. 1988). Likewise, accidents happen in the field of the industrial worker as a result of hypovigilance. Although the impact on society is not as large as the previous examples, an accident within this field could still lead to personal injury or to economical loss.

In order to prevent sleep-related incidents to happen, technical support systems, so-called Hypovigilance-Management-Systems (HVMS(s)), are developed. These systems detect hypovigilance via sensors and according algorithms, warn the individual prior to hazardous situations and, optionally, provide a vigilance-maintaining function to keep the user alert for a certain period of time, usually until he/she can securely end the current task and take a rest. However, a HVMS can improve safety only if the communication between the HVMS and the user, by means of the human-machine-interface (HMI), works properly.

Within the EU co-founded project SENSATION (SENSATION 2004), an unobtrusive and wireless HVMS is developed, which can be applied in various application scenarios, ranging from the transport sector over monitoring tasks to industrial workers. In order to reduce development effort and, thus, work cost efficient, not a specific HMI for each application field should be developed, but rather one universal HMI, suitable for all applications fields.

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[1] The term hypovigilance origins from the French language. It consists of the word *vigilance* and the Greek prefix *hypo*. Hypo means diminished. Thus, hypovigilance can be defined as a state of diminished vigilance.

1.2 Objectives of Research

Until now, the effectiveness of the SENSATION HVMS has not been validated for the field of the industrial workers. Most investigations have been focusing on immobile users, such as car drivers. However, the industrial worker is mobile and this could have a major influence on the effectiveness of the SENSATION HVMS. Therefore, it was be tested in an experimental setting, if the performance of the industrial worker was affected positively when using the SENSATION HVMS.

1.3 Structure of Master Thesis

In the next chapter, named *Application Field of the Industrial Worker*, the characteristics of the work tasks of the industrial worker are lined out and it is explained why hypovigilance is an important issue in this field of application. To be able to design and control the experiment, background information about sleepiness is needed. This information is given in the chapter named *Influence of Sleepiness.* In the same chapter, choices for the experiment are made as well. In the chapter *SENSATION HVMS*, the warning strategy and the elements of the SENSATION HVMS are described in detail. In the *Research Questions and Hypotheses* chapter, the exact research questions and hypotheses are formulated. To be able to test the effectiveness of the SENSATION HVMS for industrial workers, a typical work task is selected and translated into an experimental test. This is described in the chapter named: *Experimental Work Task.* The *Method* chapter gives an overview over the structure of the experiment. It provides information about the experimental design, the people who participated, the laboratory setting and it provides information about the procedure followed. The outcomes of the experiment are presented in the *Result* chapter. In the *Discussion* chapter, the meaning of these outcomes with respect to the research question and hypotheses is discussed.

An overview over the structure of this master thesis is given in figure 1.1.

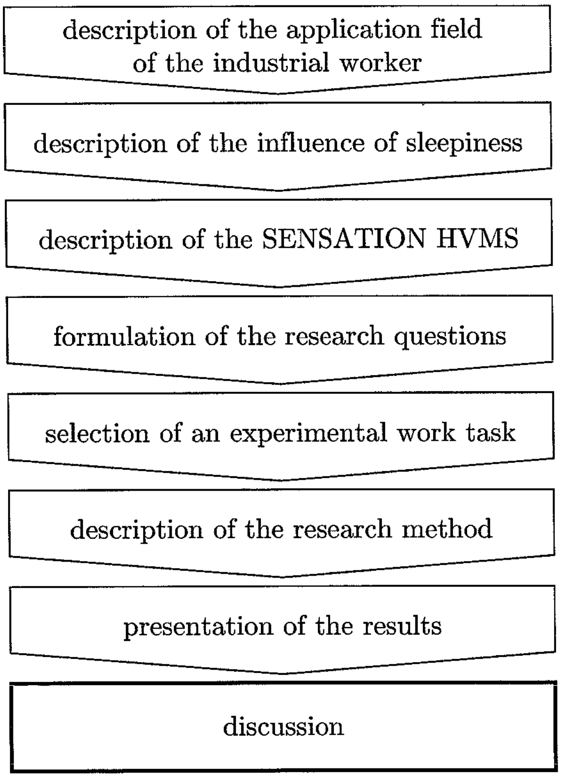


Figure 1.1: Structure of the Master Thesis

2 Application Field of the Industrial Worker

The experiment focuses on the field of application of the industrial worker. Therefore, it is important to understand what kind of different work tasks are conducted by these workers. To do so, the concerning industry sector is described and some examples of typical tasks only are provided due to the large dimension of this field. Furthermore, it will be clarified why hypovigilance is an important issue in this field of application.

2.1 Selection of Sector

There are many different kinds of industries, and they are usually divided into different sectors (e.g., Wikimedia Foundation Inc. 2007). The *primary sector* of industry is agriculture, mining and raw material extraction. The *secondary sector* of industry is manufacturing. The *tertiary sector* of industry is service production. Sometimes one talks about a *quaternary sector* of industry, consisting of intellectual services.

In this master thesis, by using the word *industrial worker*, an employee of the secondary sector is meant. This sector generally uses the output of the primary sector to manufacture goods or products to a point where they are suitable for use by other businesses, for export, or sale to domestic consumers. Many of these industries require factories and machinery to convert the raw materials into goods and products.

Divisions of the secondary sector include (Wikimedia Foundation Inc. 2007):

- Aerospace manufacturing
- Automobile manufacturing
- Brewing industry
- Chemical industry
- Clothing industry
- Electronics
- Engineering
- Energy industry (including the production of petroleum, gas and electric power)
- Industrial equipment
- Metalworking
- Steel production

- Steel industry
- Software engineering
- Telecommunications industry
- Tobacco industry

Special interest is paid to the division of metalworking because it covers a large group in the field of application of the industrial workers. The machines and materials in the metalworking division are often dangerous to use and, therefore, a single mistakes could lead to a personal injury or to an economical loss.

2.2 Examples of Work Tasks in the Metalworking Division

In the metalworking division, the tasks of the industrial worker could be divided into five catagories (Wikimedia Foundation Inc. 2007). Each category is clarified with one or more examples (see also figure 2.1):

- Shape modifying by material removal processes
  (e.g., milling, turning, cutting, drilling and grinding)
- Shape modifying with material retention processes
  (e.g., casting, plastic deforming, powder forming and sheet metal deforming)
- Joining processes
  (e.g., welding)
- Hand fabrication
  (e.g., using hand tools for assisting the fabrication process)
- Preparation and validation
  (e.g., measuring and marking out)

2.3 Task Characteristics that Contribute to Hypovigilance

The main objective of the SENSATION HVMS is to prevent sleep-related incidents to happen. Hence, it is important to get insight in typical factors of the metalworking division that could affect the hypovigilance of the industrial worker.

In the first place, it depends on the combination of task characteristics, such as: *the complexity of the task, the degree of monotonousness, the degree of automation, the amount of time needed to fulfill a single action, the degree of mobility, the regularity of occurrence of unusual facts, the kind/frequency of system feedback and the impact of a mistake.* For example, a monotonous task which has a long duration, could enhance performance decrements (Bonnet 2000).

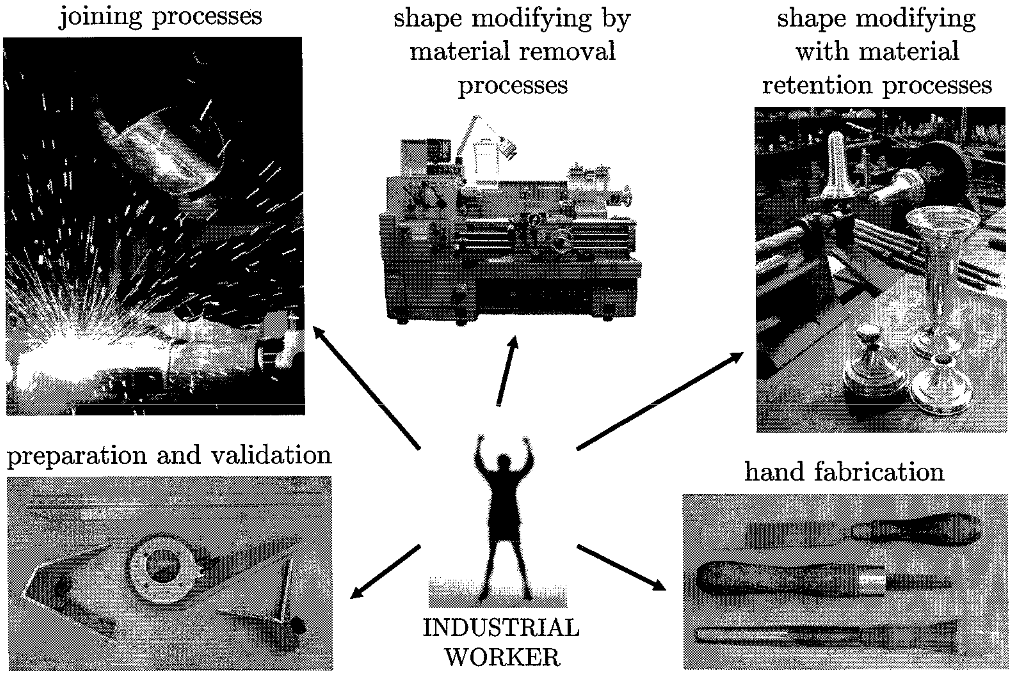


Figure 2.1: Application Field of the Industrial Worker (source: Wikimedia Foundation Inc. 2007)

Besides these charateristics, special attention should be paid to the work schedule of the industrial worker. Night shift work, rotating shifts and unsuitable break patterns could affect the level of vigilance of the industrial worker also. It is expected that the SENSATION HVMS should be most effective under these conditions because it induces sleepiness. Therefore, these conditions are described in detail in this section.

2.3.1 Shift Work

Industrial workers are often involved in shift work. Work hours are arranged in schedules with two or more shifts a day (e.g., work hours arranged in a three shift schedule: the first shift goes from 0:00 a.m. to 8:00 a.m., the second shift goes from 8:00 a.m. to 4:00 p.m. and the third shift goes from 4:00 p.m. to 0:00 a.m.). A member of a night shift team practices his/her employment at night (e.g., from 0:00 a.m. to 8:00 a.m.). A member of a rotating shift team practices his/her employment sometimes at daytime, sometimes at evening and sometimes at night according to a fixed schedule.

There could be several reasons for a company to introduce shift work schedules. Machines could be so expensive that they need to be operated 24 hours a day, 7 days a week to be profitable. Another reason could be the high demand for products. To meet these demands, it is needed to work in a three-shift schedule.

Industrial workers experience the adjustments to the night work cycle as problematic, especially when their schedule rotates regularly. In the weekends, night shift workers often shift back to the ordinary cycle to be able to participate in social activities. Therefore, working at night leads to an increased risk of serious human, environmental and economic losses (Dinges, 1995; found in Sallinen et al. 1998).

According to van den Berg (2006) there are individuals whose sleep pattern or sleep quality is not essentially affected by night schedules or rotating schedules. Other individuals are more affected as such schedules disturb their sleep-awake cycle. It should be noted that besides the conflict between displaced work hours and circadian rhythm, sleep loss is another cause for sleepiness.

2.3.2 Unsuitable Break Pattern

The break pattern of an industrial worker can have a big impact on his/her performance across the workday. Tucker et al. (2003) have shown that regular breaks seem to prevent accidents in industrial settings. Breaks are important because they give the industrial worker the opportunity to recover from his/her work. Companies usually schedule these breaks at fixed times across the workday and give them a fixed duration. The disadvantage of this procedure is that it does not always match the individual's "down times".

However, there are several reasons why it could be difficult for an industrial worker to create an individual break schedule or to take a break besides the fixed breaks. For instance, a superior officer could have explicitly forbidden to create an individual break schedule or to take additional breaks. Another reason could be a social norm that is active in a factory. It could forbid employees to differ from the scheduled break pattern. Someone who violates a social norm could get inpopular in his/her team. Therefore, most industrial workers are motivated to keep working until a break or the end of the shift is reached.

Moreover, workload could also have an impact on someone's break pattern. An industrial worker who has a production target that is difficult to achieve is probably more likely to shorten or to skip his/her breaks.

2.3.3 Conclusion

In conclusion, several task charateristics could have a negative influence on the level of hypovigilance of the industrial worker. This could lead to increased risk taking and unsafe work practices.

To validate the effectiveness of the SENSATION HVMS, these conditions have to be simulated in an experimental setting. For this purpose, each participant will take part in two experiments. At the first experiment, participants will fulfill a typical task of an industrial worker, but without suffering of hypovigilance (e.g., daytime shift). At the second experiment the same participants will fulfill the same task, but in contrast to the first experiment, this time they *will* suffer of hypovigilance (e.g., night shift). The outcomes of both experiments will be compared to measure if the difference in the level of vigilance is realized.

In the next chapter, it is described how hypovigilance could be simulated, which variables should be taken into account and how these could be measured.

3 Influence of Sleepiness

Sleep can be described as a state of natural rest. It is characterized by perceptual disengagement from and lack of responsiveness to the environment. Zimbardo et al. (1995) assume that conservation and restoration may be the most important functions of sleep. On one hand, sleep may have evolved because humans tried to conserve energy when there was no need to look for food, mates or work (Allison and Cicchetti 1976). On the other hand, sleep enables the body in housekeeping functions to restore itself in a certain way.

Human beings need to sleep. It is not a matter of choice, it is essential and inevitable. The longer someone stays awake, the greater the need to sleep and the more difficult it is to resist falling asleep. Sleep will eventually overpower the strongest intentions and efforts to stay awake (NCSDR/NHTSA 1998). Sleepiness at work is associated with an increased risk of accidents.

The SENSATION HVMS should assist those industrial workers who suffer from the negative effects of hypovigilance. In order to simulate the unfavorable characteristics of their work task for the experiment, a basic understanding of sleep, sleepiness and their influencing factors is needed. Choices for the experiment are made as well in this chapter.

3.1 Definition of Sleep-Related Terms

In the research area of sleepiness, many definitions are used in different and inconsistent ways. Therefore, a definition of sleepiness and other important sleep-related definitions is (based on: Merriam-Webster 2003):

Sleepiness is the readiness to fall asleep.

Fatigue is the weariness or exhaustion from labor, exertion or stress.

Tiredness is the state of being drained of strength and energy.

Drowsiness is the state in which sleep is induced or tends to be induced.

Weeß et al. (1998) characterize sleepiness by its underlying attention-related constructs. These can explain the functional impairments caused by sleepiness. Three attention-related aspects form the basis:

Alertness precedes attention and refers to the activation of the central nervous system and exists out of two parts: The *tonic* part of this construct is mostly dependent on circadian changes and, thus, not under conscious control. It describes, e.g., the feeling of wakefulness of a person from one day to another. The *phasic* part is dependent on intermitting stimuli, mainly warning stimuli, which lead to a shorthanded rise of alertness. It describes, e.g., the rise in alertness of a person sitting quietly in chair when called.

Vigilance can be defined as "a state of readiness to detect and respond to certain specified small changes occurring at random time intervals in the environment" (Mackworth 1957).

Attention can be divided into selective and divided attention. *Selective attention* is the ability to select and focus on a single stimulus which is part of a large set of stimuli. *Divided attention* is the ability to quickly and parallel process information in an automated but controlled matter.

Considering the aspects described above, sleepiness mainly refers to the grade of central nervous stimulation (i.e., alertness) and consequently, influences the individual performance capabilities in terms of vigilance and attention (Weeß et al. 1998). In this master thesis, vigilance is defined as a measure in which the above constructs are positively represented.

3.2 Influencing Factors for Sleepiness

To be able to validate the SENSATION HVMS, the participants need to be sleepy at the experiment. In this section, influencing factors for sleepiness are described. They are used to simulate the negative effects of shift work and unsuitable break patterns. Sleep disorders will not be discussed (e.g., insomnia, narcolepsy and sleep apnea), as they cannot be used to create sleepiness in healthy participants.

3.2.1 Sleep Deprivation

Different human beings have different sleep requirements. For adults, the daily duration of sleep is about 8 hours (Sleep Research Society 1997). If this duration is not reached, a sleep dept is created. Sleep dept can be reduced by sleeping more than what is required daily.

Sleep dept is caused by sleep deprivation. In the literature, a distinction between *partial* and *total* sleep deprivation is made (e.g., van den Berg 2006; Popp 2005). Partial sleep deprivation can be defined as the reduction of total sleep time (e.g., sleep 4 hours in stead of 8 hours). Total sleep deprivation can be defined as the total ignorance of sleep time by staying awake over night. If sleep deprivation is repeated over a period of time, it can affect behavior and cognitive functions, like attention, speech and memory (Zimbardo et al. 1995). However, these disturbances can be reversed by sleeping more than required for one or more days.

In the experiment, sleep deprivation can be used to simulate the negative effects of shift work and unsuitable break schedules on sleepiness. For this reason, two days before the experiment, the participants need to follow a special sleep pattern. Partial sleep deprivation should make the participants a bit sleepy two days before the experiment. Additionally, a night with total sleep deprivation just before the experiment will make them very sleepy.

It should be noted that the effect of sleep deprivation depends on age. A study of Philip et al. (2004) has shown that 24 hours of total sleep deprivation affected the reaction time of the young participants (20-25 years) negatively while the reaction time of the older participants (52-63 years) remained almost unaffected. Thus, for the experiment, it is better to use young participants, because they are more vulnerable to the effects of sleep deprivation.

3.2.2 Circadian Rhythm

Human beings have the ability to keep track of time by using something like an internal clock. It follows a pattern that repeats itself approximately every 24 hours. This is better known as the circadian rhythm. It is primarily influenced by the light-dark cycle and its function is to adjust daily life to a diurnal rhythm (Zimbardo et al. 1995). A change in circadian rhythm corresponds to changes in physiological activities of the nervous system. Arousal levels, metabolism, heart rate, body temperature and hormonal activity change depending on the indication of time of someone's internal clock. As a result, the individual's maximum propensity to be active lies at certain phases during the daily temporal span. Thus, the time of day at which the experiment is conducted strongly influences the effects of the sleep deprivation.

Human beings experience two dips daily (circadian "down" phases) and two peaks (circadian "high" phases) in performance. A strong circadian "down" phase generally manifests between 3 a.m. and 4 a.m. (afternoon) as well as between 4:00 p.m. and 8:00 p.m. (midnight/morning). In the same way, a circadian "high" phase generally manifests between 8:00 a.m. and 12:00 a.m. (morning) as well as between 4:00 p.m. and 8:00 p.m. (afternoon/evening). According to Åkerstedt (2006), 90 percent of the people show severe sleepiness from 4:00 p.m. till 8:00 p.m.. It has a massive effect on someone's alertness. The afternoon dip is not as massive as the midnight/morning dip and it is very narrow, which makes it difficult to hit. In sum, the best time to run the main experiment is between from 4:00 p.m. till 8:00 p.m..

3.2.3 Morningness–Eveningness Questionnaire

It should be noted that some individuals prefer one circadian "high" phase over the other (e.g., Foret 1982, Kerkhof and van Dongen 1996, found in: Louzada et al. 2004). Individuals with a relatively early circadian "high" phase are called morning-types. Those with a relatively late circadian "high" phase are called evening-types. In the experiment these differences of chronotype could lead to individual differences in performance.

The Morningness–Eveningness Questionnaire (MEQ) of Horne and Östberg (1976) was used to determine which participants were morning-types and which participants were evening-types. The MEQ consists of nineteen multiple choice questions, with each answer being assigned a value. Their sum gives a score ranging from 16 to 86. High scores (59-86) identify morning-type individuals, low scores (16-41) correspond to evening-types, and scores from 42 to 58 refer to an intermediate type. For the experiment the German version of the MEQ was used, named: D-MEQ (see appendix A).

3.3 Countermeasures Against Sleepiness

For the experiment, it is important to get insight in measures that could counteract the sleepiness induced by the sleep deprivation and the time of day at which the experiment takes place. When the participants counteract the induced sleepiness, it does not make sense to validate the SENSATION HVMS.

This section focuses on short term countermeasures that are widely used.

3.3.1 Sleep, Naps and Breaks

There is little evidence that taking a break significantly influences sleepiness. However, according to Åkerstedt et al. (2004) it is assumable that sleep at work or naps before or during work is an effective, probably the most effective countermeasure against sleepiness. The effectiveness of a nap probably depends on the length and the timing.

A study of Sallinen et al. (1998) suggests that a short nap, i.e., less than 1 hour, is a good countermeasure against sleepiness during a night shift. However, it is not possible to restore to the alertness level which was available the beginning of the shift. It was noticed that, during the first 10-15 minutes after awakening from a short nap, sleep inertia may occur. This is a short impairment of performance directly after waking up.

According to Hagenmeyer et al. (2005), a nap of 10 minutes is enough to restore. This time is needed to reach the first stage of a deep sleep, i.e., muscle relaxation. Therefore, breaks with a maximum duration of 10 minutes are allowed in the experiment. In this way, the opportunity is offered to recover and not too much valuable test time is lost.

3.3.2 Food and Drinks

Food and drinks containing caffeine and other methylxanthine stimulants belong to the most used countermeasures against sleepiness. For instance, these stimulants can be found in coffee, cola, chocolate, cacao and in green/black tea.

Caffeine can decrease sleepiness and fatigue for healthy individuals (Zwyghuizen-Doornebos et al. 1990, found in: Popp 2005). Energy drinks contain large amounts of caffeine. Reyner and Horne (2002) tested the effect of energy drinks on sleepy participants in a driving simulator (found in: Popp 2005). The result showed that the group that drunk energy drinks clearly made less mistakes than the the control group. It was assumed that energy drinks could be helpful to reduce sleepiness during a long and monotonous drive, when suffering from sleep deprivation.

Thus, to avoid that the participants to counteract the effects of sleep deprivation, they are told that they are not allowed to consume food and drinks containing caffeine and other methylxanthine stimulants before and during the experiment.

3.3.3 Environmental Stimulation

Several studies have shown that loud sounds and noises only have a weak positive effect on performance of sleep deprived individuals (e.g., Wilkison 1963, Hartley and Shirly 1977, Tassi et al. 1993, found in: Popp 2005). Presumably, this effect is caused by an unspecific increase of the arousal level and, as a consequence, an increase in the ability to stay awake.

There are no clear findings for the temperature as countermeasure against sleepiness.

3.3.4 Physical Activation

Physical activation can cause a short term improvement in performance, lasting for about 5 minutes (Bonnet 2000). Likewise, physical activation has a positive short time influence on psycho-motor performance that was affected by sleep deprivation. (Wilkison 1965, found in: Popp 2005). However, after 40 hours of sleep deprivation, decreasements in performance could not be compensated by physical activation (Moses et al. 1977, found in: Popp 2005) anymore.

It should be kept in mind that an experimental task which requires a lot of movement could counteract the effect of the sleep deprivation.

3.4 Measurement of Sleepiness

In this section, both objective and subjective measures of sleepiness are described. A brief overview is presented and only those methods that are important in the context of the experiment are described in more detail.

3.4.1 Objective Measures

Objective measures can be divided into *behavioral* measures and *(electro-)physiological* measures.

3.4.1.1 Behavioral Measures

Sleepiness leads to behavioral changes. Characteristics of these changes can be used as indicators for sleepiness.

It is possible to judge body postures, facial expressions and mannerisms to determine the level of sleepiness of an individual. This simple, unobtrusive and reliable measurement method is based on a rating system. Wierwille and Ellsworth (1994) showed that the level of sleepiness of vehicle operators could be estimated on characteristics such as facial tone, slow eyelid closure, and mannerisms (rubbing, yawning, nodding, etc.). They created a continuous scale containing five descriptors to allocate the sleepiness characteristics (see also appendix C): *not sleepy*, *slightly sleepy*, *moderately sleepy*, *very sleepy* and *extremely sleepy*. This rating scale will be used to judge the sleepiness of the participants during the experiment, and its outcome will be used as input for the SENSATION HVMS (see also the next chapter: SENSATION HVMS). Vöhringer-Kuhnt et al. (2004)

have tested this rating method against objective EEG data. Their results indicate, that sleepiness evaluation by trained raters is a stable and reliable measurement, which can be achieved by relatively simple and straightforward means.

Moreover, the decrease in functioning and performance on specific work tasks can be used as an indicator for sleepiness. This approach has been validated in several studies with experimentally induced sleep deprivation (e.g., Bonnet 2000). Performance tests can be divided into *psycho-motor tests* and *cognitive tests*, in which reaction time and/or the number of errors are measured. However, ideally, the test conditions should evaluate aspects of performance that are relevant to target daily activities. For the experiment, performance test can be used simulate a typical task of the industrial worker.

Body movements can be measured by *actigraphic monitoring.* It is usually conducted by a small device. It records and stores the activity of the arm. Absence of movements over several minutes is an indicator of sleep. Thus, an actigraph makes it possible to discriminate between sleep and wake phases as well as to estimate sleep duration. In the experiment, actigraphic monitoring is used to check if the participants stayed awake during the sleep deprivation.

3.4.1.2 (Electro-)Physiological Measures

These tests have high relevance in the context of sleep research and sleep disturbance treatment. Examples of these test are: *multiple sleep latency test*, *maintenance of wakefulness test*, *pupillometry* and *cerebral evoked potentials.* For the development and evaluation of the HMI-elements of the SENSATION HVMS their use is restricted, although it is to be mentioned that pupillometry might be useful to measure alertness in specific cases. Consequently, no further description is included in this master thesis.

3.4.2 Subjective Measures

Subjective rating scales for sleepiness are holistic measures that are easy to use and require little expertise in administration and interpretation of the results. However, one should take into account that these scales are vulnerable to misinterpretations by the users. People tend to evaluate their sleepiness by looking at fatigue and tiredness symptoms. Moreover, the severity of sleepiness is underestimated. With increasing sleepiness, the ability to accurately judge one's own level of sleepiness decreases. Two well known subjective rating scales are frequently used, the *Stanford Sleepiness Scale* (SSS) and the *Karolinska Sleepiness Scale* (KSS).

The SSS is used to asses the momentary degree of sleepiness. This scale is very helpful to measure differences during a given time epoch. On a seven-point scale one statement has to be chosen. The scale ranges from: *(1) feeling active*, *(2) vital*, *(3) alert*, *(4) wide awake*, *(5) no longer fighting sleep*, *(6) sleep onset soon* to *(7) having dream-like thoughts.* It should match with someone's inner judgment of the degree of sleepiness.

Comparable to the SSS, the KSS measures differences in sleepiness during a given time epoch. On a continuous nine-point scale with five statements the momentary degree of sleepiness has to filled out (see appendix B). The five statements range from: *(1) very* *alert, (2) alert, (3) alert nor sleepy, (4) sleepy, but no problems to stay awake* to *(5) very sleepy, great effort to stay awake (fighting sleep).* Between these statements, four empty graduations are located. These could be marked as well, if a someone is in doubt between two statements. KSS seems to be a good scale to measure the subjective sleepiness rating of the participants at the experiment. It requires less reading than the SSS and can be filled out faster.

4 SENSATION HVMS

As outlined in previous chapters, sleepiness can lead to severe incidents with serious consequences for the industrial worker and its environment. In order to prevent such incidents, the SENSATION HVMS was developed. In principles, this technical device measures the state of sleepiness of the respective user and takes according measures if a critical state of sleepiness with respect to the work task of the user is reached. On one hand, the user is warned and informed about his/her state of sleepiness, on the other hand the system might try to keep the user awake for a certain time (if at all possible) in order to enable the user to finish dangerous actions.

In order to understand how the industrial worker is warned by the SENSATION HVMS, its basic elements, warning strategies and HMI-elements are described in this chapter.

4.1 Basic Elements

Basically, the SENSATION HVMS consists of three parts: *sensors to collect data*, *an expert system to process the data* and *a set of human machine interface elements which enable the communication with the user* (see figure 4.1).

Relevant data for the measurement of the sleepiness state of the user is gathered by different sensors. In order to reduce traffic on the system communication network, these sensors include a basic pre-processing of data. For example, a camera-based eye-lid-movement sensor does not transmit video data, but information about the eye lid movement such as lid closure time etc.. The sensors communicate with the central system via defined networks: Sensors used close to the body are connected to a body area network (BAN); other sensors such as cameras on the dashboard of a car are directly connected to the local area network (LAN).

The pre-processed data coming from the sensors to the expert system, in a first step, are combined by means of according algorithms to a vigilance vector, i.e., a vigilance value on a simple scale augmented by the certainty of this value. The warning strategy is implemented in a decision-of-action-to-take-manager; with respect to the use context, it takes the actual sleepiness state of the user into account in combination with surrounding variables such as the risk level of the actual situation. The action decided in this way is communicated to the user through the respective HMI-elements, which are connected to the expert system though the same BAN/LAN-structure that serves the sensors.

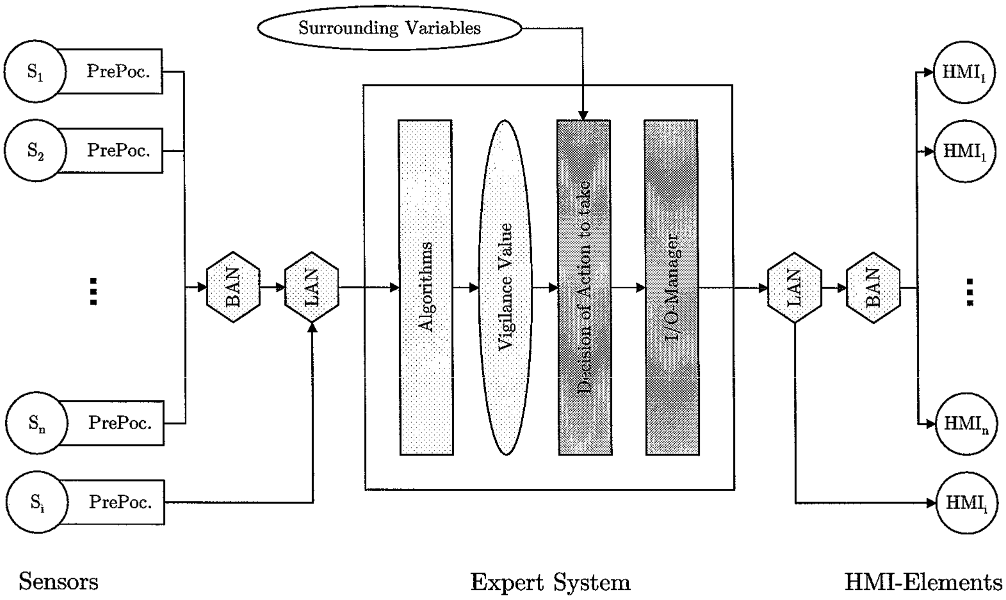


Figure 4.1: Structure of the SENSATION HVMS (based on: Hagenmeyer et al. 2005)

4.2 Warning Strategy

Wickens et al. (1998) stated that "the goal (of a warning) is to get the user to comply with the warning and, therefore, use the product in a safe way, or avoid unsafe behavior". Following their findings, four crucial elements need to be satisfied by the SENSATION HVMS. The SENSATION HVMS first needs to draw the *attention* of the user, then make sure that the warning message itself will be physically *perceived* by the user and finally will be cognitively *understood* and, moreover, *accepted.* The first two items mainly refer to the physical setup of the HMI-elements, i.e., to the perceptive channels chosen and to the detailed characteristic of the signal. The latter two points mainly refer to the strategy by which the user is addressed.

4.2.1 Communication Modes

The warning strategy of the SENSATION HVMS outlines the basic sequence of the human machine communication. It can be separated into three modes: *normal mode*, *warning mode* and *vigilance-maintaining mode.*

4.2.1.1 Normal Mode

The current state of sleepiness of the industrial worker is the basic input to the warning process. In the normal mode, the information about the sleepiness status is continuously presented in a way that it is not disturbing the user. It is recallable at any time without big effort.

4.2.1.2 Warning Mode

The warning mode is activated when the user reaches a predetermined sleepiness threshold. Within this mode, dependent on the current state of sleepiness of the user and the potential risk of the situation, either a *cautionary* or an *imminent* warning is displayed. However, the effectiveness of a warning dependeds on the personal abilities and willingness of the industrial worker to comply with the warning.

4.2.1.3 Vigilance Maintaining Mode

If the imminent warning is ignored, a *Vigilance Maintaining Mode* (VMM) is activated with the aim to keep the user alert for a certain period of time, usually until he/she can securely end the current task and take a rest. Such devices are discussed controversially, as they might encourage the user to behave more hazardous than he/she would do without an vigilance maintaining device. For example, an industrial worker might prolong his/her task despite being sleepy, but no technical system can guarantee to keep individuals alert for the next two hours.

Landström et al. (1998) found that a specific disharmonic sequence of sounds that is played back at arbitrary times significantly increase wakefulness. The VMM uses these Landström sounds to keep industrial workers alert over a certain period of time. The VMM randomly generates disharmonic sounds, which last around 4 seconds and are presented in irregular intervals of up to 5 minutes.

4.2.2 Communication Structure

The communication structure of the SENSATION HVMS distincts five states of vigilance was made: *awake*, *drowsy*, *very drowsy*, *drowsy systrophe* and *awake systrophe*. Figure 4.2 shows the state diagram of the SENSATION HVMS and the possible actions of the system.

The five blocks represent the actual vigilance state of its user. The circles with the numbers one to seven represent the system states with according action of the SENSATION HVMS. The arrows present the transitions between the several states. In table 4.1, the exact descriptions of the user's states and according actions are described. The normal mode is active in states 1, 4 and 7. The warning mode is present in states 2 and 6 (cautionary warning) and states 3, 5a and 5b (imminent warning). The VMM is active in states 3, 5a and 5b.

4.3 Design and Operalization of the HMI-Elements

The SENSATION HVMS contains three HMI-elements, which establish the communication with the user: *wrist unit*, *belt unit* and *headphone*. They are the physical representation of the warning strategy. SwichBoard is the "brain" of the SENSATION HVMS. It drives the HMI-elements by applying the previously described warning strategy. In this section, the design of the three HMI-elements and the driving system are clarified.

Circle	Status of User	Status on Display	Acoustic Alarm	Vibrotactile Alarm	Speech Message in German (always after acoustic/vibrotactile alarm)	User Feedback	VMM
1	awake	green	none	none	none	no	off
2	drowsy	yellow	beep 2x	vibration pulse 2x	Sie sind schläfrig. Ihre Sicherheit ist gefährdet. Machen Sie eine Pause. Bestätigen Sie diese Nachricht bitte mit dem Bestätigungsknopf.	yes	off
3	very drowsy	red (+ white blinking LED)	beep 2x (loud)	pulsed vibrations	Sie sind extrem schläfrig. Es besteht eine hohe Unfallgefahr. Machen Sie sofort eine Pause. Gönnen Sie sich mindenstens 5 min. Schlaf. Bestätigen Sie diese Nachricht bitte mit dem Bestätitigungsknopf. Das Wachhaltesystem wird aktiviert. Es dient zur kurzfristigen Aufmerksamkeitssteigerung. Es kann jedoch keinen Schlaf ersetzen.	yes	activated after user feedback
4	awake after drowsy	green	beep 1x	none	none	no	off
5a	drowsy after very drowsy (from circle 3)	red	only in combination with VMM		none	only in combination with VMM	on
5b	drowsy after very drowsy (from circle 7)	red	beep 2x	vibration pulse 2x	Sie sind sehr schläfrig. Es besteht eine erhöhte Unfallgefahr. Machen Sie sofort eine Pause. Gönnen Sie sich mindesten 5 min. Schlaf. Bestätigen Sie diese Nachricht mit dem Bestätigungsknopf. Das VMM wird aktiviert. Es dient zur kurzfristigen Aufmerksamkeitssteigerung. Es kann jedoch keinen Schlaf ersetzen.	yes	on
6	drowsy systrophe	yellow	beep 2x	vibration pulse 2x	Sie sind sehr schläfrig. Es besteht eine erhöhte Unfallgefahr. Machen Sie sofort eine Pause. Gönnen Sie sich mindesten 5 min. Schlaf. Bestätigen Sie diese Nachricht mit dem Bestätigungsknopf.	yes	off
7	awake after very drowsy	yellow	beep 1x	none	Es wird keine Schläfrigkeit mehr gemessen. Die VMM wird ausgeschaltet. Bestätigen Sie diese Nachricht mit dem Bestätigungsknopf.	yes	deactivated

Table 4.1: Possible Actions of the SENSATION HVMS (based on: Hagenmeyer et al. 2005)

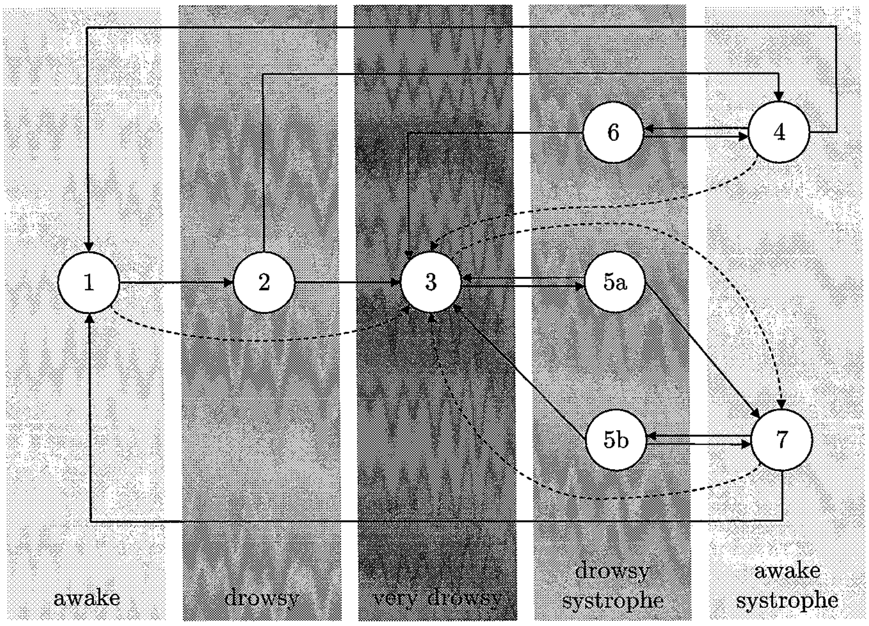


Figure 4.2: State Diagram of the SENSATION HVMS (based on: Hagenmeyer et al. 2005)

4.3.1 Wrist Unit

The wrist unit is a device that can be worn around the wrist like an ordinary watch. It contains a status indicator and two buttons, see figure 4.3.

The status indicator presents the current sleepiness status of the user in an unobtrusive way. The wrist is not necessarily in the field of view of the user and, therefore, the information has to be recalled actively.

The status indicator contains a group of 4 *green* LED's, a group of 4 *yellow* LED's and a group of 4 *red* LED's. They are positioned in line at top of the transparent arc. Depending on the level of sleepiness of the user, one of the three LED groups is activated.

A confirmation button is located at the center of the transparent arc. A bright white flashing LED is integrated in this button. It is activated in the case of immedient alarms. The blinking LED is deactivated by pressing the button.

The SENSATION HVMS is able to provide spoken messages. The user can repeat these by pressing a small button on the side of the wrist unit.

4.3.2 Belt Unit

The belt unit is a small box (see figure 4.4) with a vibrating motor. The box includes a holding for the attachment to a belt. The belt unit generates vibrotactile signals to catch the user's attention and to warn for a decreased attention. The most preferred positioned for the belt is on the side of the haunch.

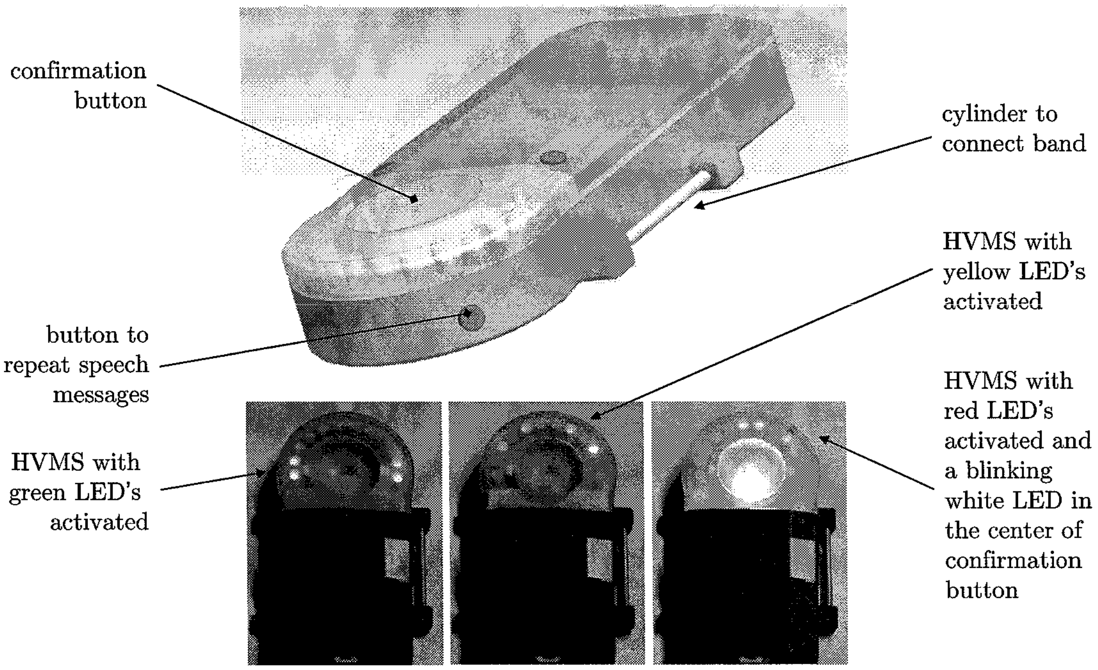


Figure 4.3: Wrist Unit of the SENSATION HVMS

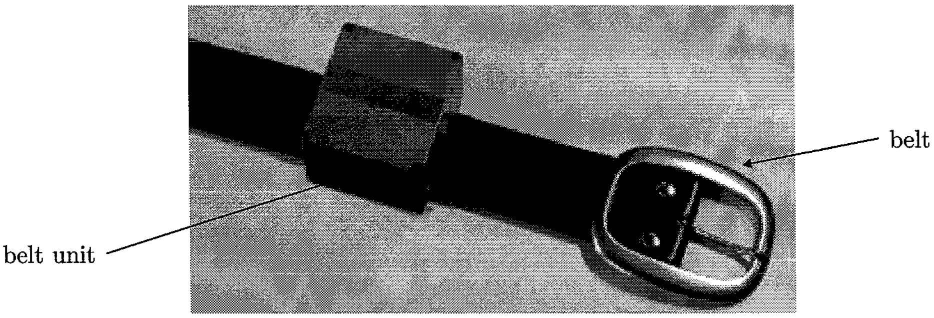


Figure 4.4: Belt Unit of the SENSATION HMVS

4.3.3 Headphone

Speech messages and acoustic alarms are presented via a headphone, see figure 4.5. This headphone is light-weight and features a hook-on design for maximal wearing comfort.

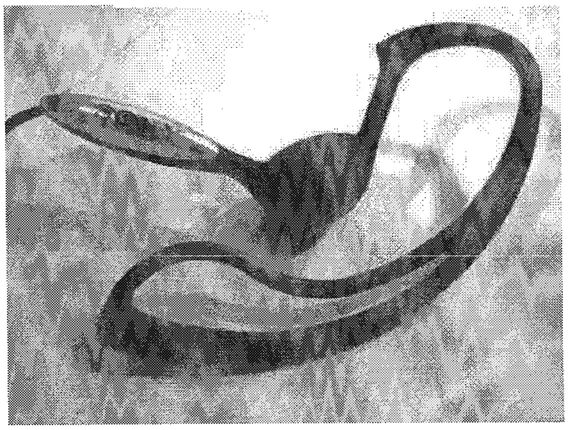


Figure 4.5: Headphone of the SENSATION HVMS

4.3.4 SwitchBoard

The SENSATION HVMS works according to the previously described warning structure. A software package named *SwitchBoard* was used to implement this structure. It drives the HMI-elements with regard to the sensory input (alertness value) and possible responses of the user.

At the time of the experiment, no sensory input was available for the SwitchBoard. Therefore, a rater judged the level of sleepiness of the SENSATION HVMS user. The rating scale of Wierwille and Ellsworth (1994) was applied for this purpose, as described in the previous chapter. At the experiment, a rater assigned a value between 1 and 5 ((1)*not sleepy*, (2)*slightly sleepy*, (3)*moderately sleepy*, (4)*very sleepy*, and (5)*extremely sleepy*), in correspondence to level of sleepiness of the SENSATION HVMS user. This value was entered in SwitchBoard by the rater. Subsequently, SwitchBoard acted in regard to the input value of the rater and to the feedback given by the SENSATION HVMS user.

To do the rating task correctly, the Wierwille's Scale is provided as assistance to the rater (see appendix C).

5 Research Questions and Hypotheses

The aim of this master thesis is to evaluate the efficiency of the SENSATION HVMS in an experimental setting. This will be done for the field of application of the industrial worker. It is assumed that the performance is affected positively, when a sleepy industrial worker make use of the SENSATION HVMS. In other words, it should reduce the number of errors made by the user and it should help the user to maintain his/her level of productivity. This leads to the following research questions:

- Does the performance of the industrial workers benefit when they take the warning strategy from the SENSATION HVMS into account?
- Is it the warning strategy of the SENSATION HVMS that causes industrial workers to maintain their performance level longer or are it the warning signals itself that causes this effect?

For this purpose, the system is tested with three groups of participants: *the treatment group*, *the control group* and *the positive control group*. A comparison of users with the SENSATION HVMS (treatment group) to the group with no warning system (control group) enables to investigate the effectiveness of the system. A further comparison of the treatment group to a group with a system providing random warning signals (positive control group) allows to find out if the results were caused by proper design of the warning strategy and the HMI-elements or if they are caused by the intervention itself.

Therefore, on the basis of the general hypothesis above, the following three research hypotheses are derived which can be evaluated empirically:

1. Users of a warning strategy with random output perform better than users without any warning strategy

   Measure 1: productivity

   Measure 2: number of mistakes

   Measure 3: combination between productivity and number of mistakes

2. Users of the SENSATION warning strategy perform better than users of a warning strategy with random output

   Measure 1: productivity

   Measure 2: number of mistakes

   Measure 3: combination between productivity and number of mistakes

3. Users of the SENSATION warning strategy perform better than users without any warning strategy

    Measure 1: productivity

    Measure 2: number of mistakes

    Measure 3: combination between productivity and number of mistakes

6 Experimental Work Task

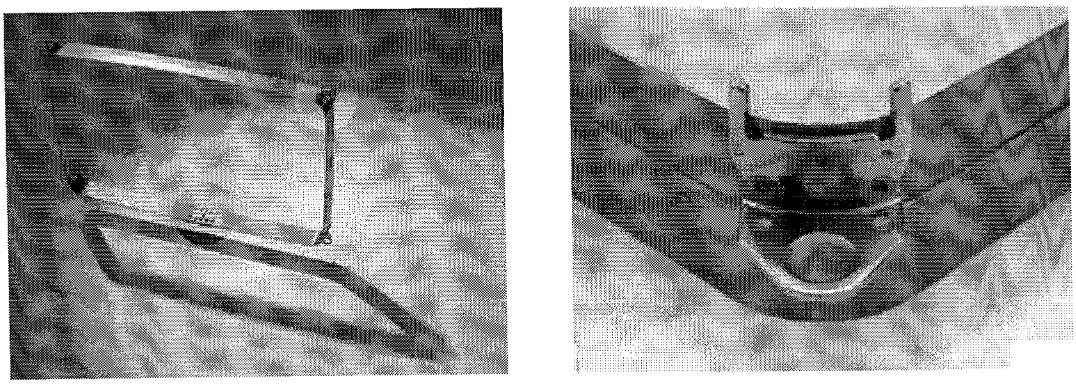
In this chapter, tests for the experiment are chosen, based on the information from the previous chapters. These tests should allow to measure differences in performance due to sleepiness of the industrial worker. Only when sleepiness is changing, the effectiveness of the SENSATION HVMS can be tested.

Therefore, a typical task of an industrial worker is selected. For testing reasons, it should be monotonous, have a long duration, have a high complexity, involves working memory, imposes external control on the industrial worker and should be lowly automated, because these factors enhance performance decrements in sleep deprived individuals (Bonnet 2000).

6.1 Resistance Welding of Rim Bands

The resistance welding of rim bands is a typical task that fulfills these requirements. Welding rim bands is a repetitive positioning task which is carried out in a three-shift schedule. It requires mobility and is known to produce different kind of mistakes (Bonnet 2000).

A rim band is a metal component of a television screen or a monitor (compare to figure 6.1a). Its function is to counter the vacuum induced tensions in the glass tube, thus increasing strength and safety of the tube. Furthermore, the rim band holding the tube is mounted into the television or monitor housing by means of stackable lugs welded to the rim band (compare to figure 6.1b).



(a) Rim Band

(b) Stackable Lug

Figure 6.1: Rim Band and Detail of a Stackable Lug (source: Matino Admeco 2006)

6.1.1 Welding Procedure

Because rim bands are produced in large quantities, their production has to be semi-automated. The operator of the welding unit carries out the following procedure (see also figure 6.2):

1. The operator positions a rim band in the center of the welding unit.
2. The operator activates the welding process by pressing the two operation buttons simultaneously.
3. The unit tightens the rim band onto its exact position.
4. The unit positions and welds the stackable lugs on each of the 90 degrees bends of the rim band.
5. The operator releases the two operation buttons when the welding process is finished.
6. The unit releases the rim band.
7. The operator removes the rim band from the unit and puts it in a storage box.

6.1.2 Dual Task

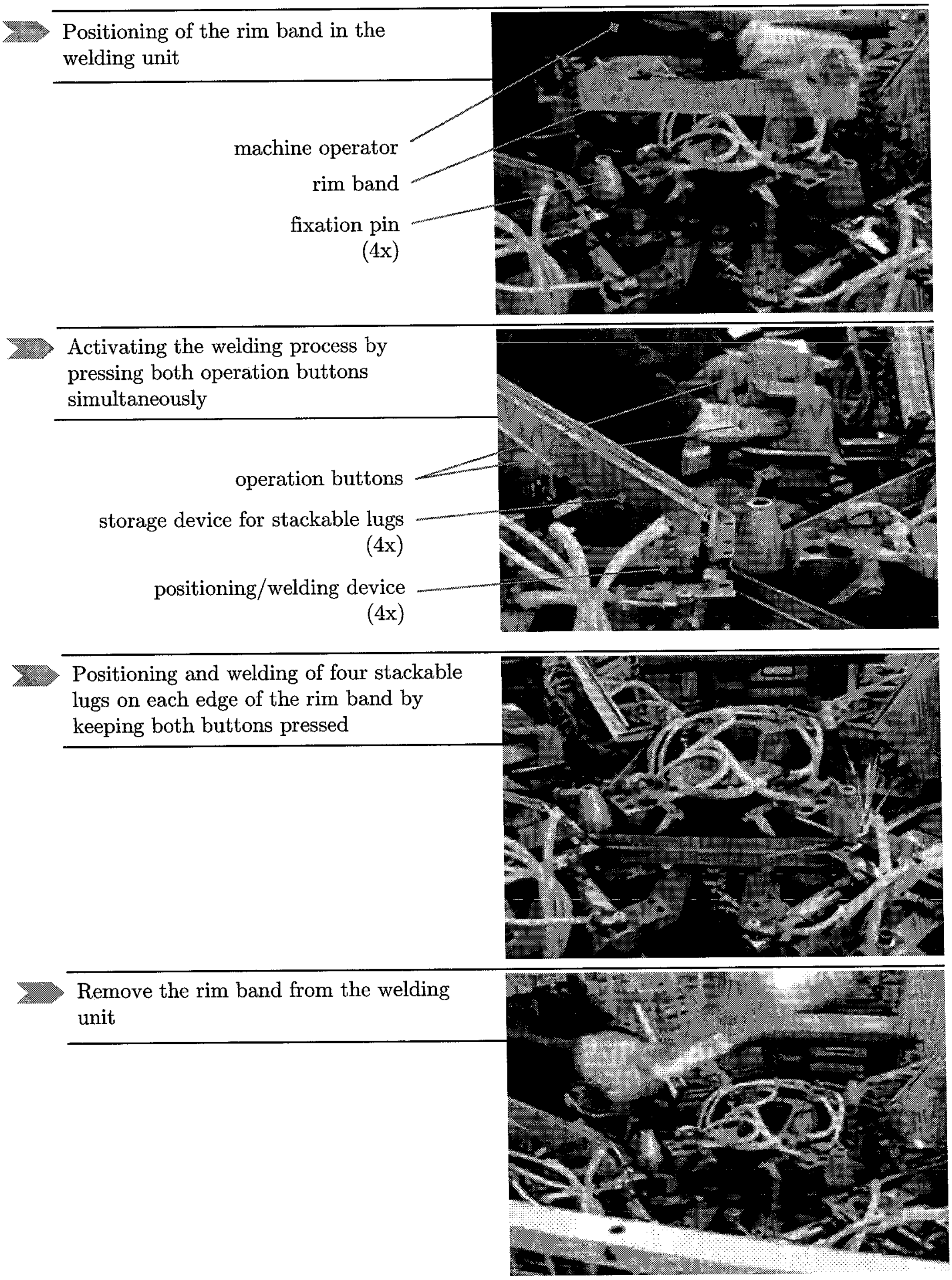
Presumably, the operator also monitors the production process of the stackable lugs which is fully automated. Hence, the industrial worker only has to ensure that the process is supplied with enough raw material and needs to remove the produced stackable lugs every time when the buffer of the production machine is (nearly) filled.

In consequence, the operator mainly is involved in rim band welding, but needs to monitor the production process of the lugs. For the operation of the latter process, he/she needs to be mobile between the two machines. This is considered as a dual task.

6.1.3 Undesirable Outcomes

An industrial worker can cause “undesirable outcomes”, i.e., errors. Dependent on the impact, the outcomes could be divided in the following categories: *production delay*, *damage to product*, *damage to tool*, *damage to machine*, *damage to building/environment* and *personal injury*.

Although it is mostly impossible to directly compare the errors (e.g., it is difficult to state how many damaged products are equal to a personal injury), these incidents can be sorted by means of an ordinal scale (e.g. personal injury is surely worse than damage to a product).



Positioning of the rim band in the welding unit

Activating the welding process by pressing both operation buttons simultaneously

Positioning and welding of four stackable lugs on each edge of the rim band by keeping both buttons pressed

Remove the rim band from the welding unit

Figure 6.2: Procedure for the Welding Process (source: Matino Admeco 2006)

6.2 Selection Criteria for the Laboratory Tasks

For reasons of cost and time, it was not possible to conduct tests with the original operators of the welding stations. Moreover, in the original work environment, it is not possible to control the surrounding conditions of the experiment adequately.

Therefore, the orginal work tasks were analyzed with respect to cognitive and motor functions and was mapped to according laboratory tasks which accurately depicted the requirements of the original task. A *psycho-motor task* was combined with a *divided attention task*, together forming a "factory test" of high practical relevance, as described in the following.

From the description of the dual task above, it is concluded that mainly psycho-motor skills and mental skills are needed for the rim band worker in order to perform well.

Psycho-motor skills depend on the degree of cooperation between mental and physical skills. A bad cooperation leads to inaccurate movement of the limbs. For the rim band worker this can result in a decrease of the ability to position rim bands accurately causing a delay in the production and/or scrap. A psycho-motor test will be used to test this skill.

For welding rim bands, perceptual speed, alertness, reasoning and (working) memory are important *mental skills*:

Perceptual speed enables the industrial worker to react quickly to stimuli in his/her environment, e.g., to rapidly note that the welding process is completed or that an error occurred.

Alertness in this specific case denotes the ability of the worker to observe relevant process parameters.

Attention, especially divided attention, in this case, denotes the ability of the worker to successfully conduct the dual task.

Reasoning, in this case, enables the worker to understand why errors occur and how they can be avoided. Especially, the worker needs to decide when he/she leaves the main process of rim band welding in order to empty the buffer of the machine producing lugs. An optimum has to be found, so that no mistakes are made and the amount of products is not affected negatively.

(Working) Memory is involved in remembering the production procedure as well as necessary steps.

In addition to the factory test, specific cognitive skills were planned to be tested with sub-tests of a standarized neuro-psychological test battery (Test of Attentional Perfomance-Mobility (TAP-M, Zimmermann and Fimm 2005)).

The selection of experimental tests is described below in detail.

6.3 Psycho-Motor Test

Several standardized psycho-motor tests are available to test gross manual movements, fine manual movements or a combination of both. The rim band welding task mainly requires gross manual movements.

A typical related, standardized test is the Stromberg Dexterity Test. This test was developed in 1945 as one means of employee selection for jobs which require speed and accuracy of arm and hand movements (e.g., assemblers or welders). The Stromberg Dexterity Test requires the applicants to discriminate and sort 54 biscuit shaped discs, which are to be inserted into a form board as quickly as possible.

Because the aim of this work was to test the HMI-elements of the SENSATION HVMS in a most natural situation, a specific psycho-motor was developed on basis of the Stromberg Dexterity Test, simulating the welding process of the rim bands under controlled conditions. The psycho-motor test made it possible to measure the hand-eye-coordination as well as alertness and attention by counting the number of correct units produced and the number/kind of mistakes made during the test.

The test utilized a "psycho-motor device", 50 rim bands and four storage devices (see figure 6.3). The psycho-motor device did not contain any moving parts and no real welding did take place. Thus, any chance on physical harm was avoided. However, the participants could still make the same kind of mistakes like the "real" industrial workers.

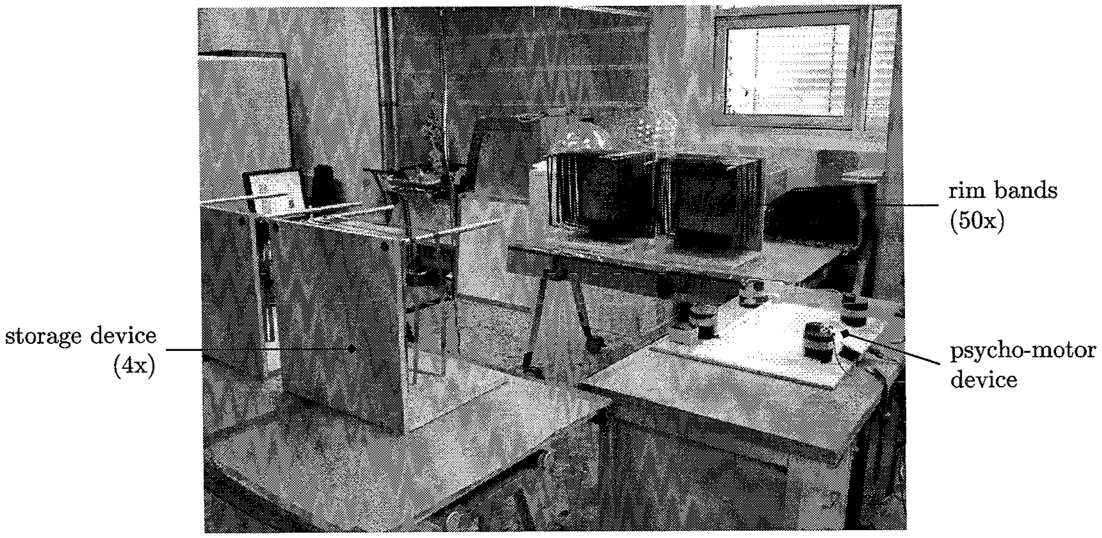


Figure 6.3: Basic Elements of the Psycho-Motor Test

6.3.1 Psycho-Motor Device

The psycho-motor device consisted of a wooden plate, four PVC-blocks, two toggle switches, a light barrier and a red LED (see figure 6.4). The PVC-blocks were mounted on the wooden plate. Each block had a slot in which one of the corners of the rim band had to be positioned. A good hand-eye-coordination was required, because the slots were only one millimeter wide. By means of the light barrier and four sub-miniature switches in the slots of the PVC blocks, it was checked if the operator had position the rim band correctly. The imaginary welding process was activated by pressing the two toggle switches simultaneously. A red LED, mounted on the middle of the wooden plate, simulated the duration of the imaginary welding process.

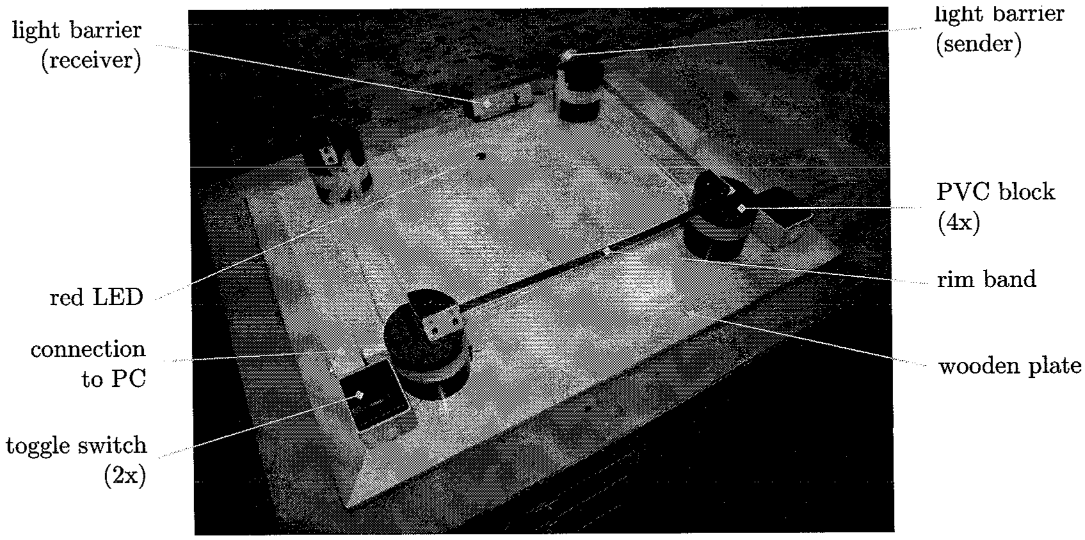


Figure 6.4: Psycho-Motor Device with a Rim Band

6.3.2 Rim Bands

The rim bands for the test were made of a steel tape of a width of 16 millimeter and a thickness of 0,5 millimeter. The steel was cut, bend, and welded resulting in a rim band with a size of 390 by 450 millimeter (see figure 6.5). Each rim band was marked with a white label indicating its orientation (front/back and left/right). This label could automatically be spotted by the light barrier. Half of the rim bands had the label at the same side as the welding spot (compare to figure 6.1), the other half had the label at the opposite side, in order to avoid too obvious indication of the orientation as the welding spot is an eye-catching marker. As rim bands had sharp edges, the participants needed to wear gloves for safety reasons.

6.3.3 Storage Device

The rim bands were difficult to pile up. In order to reduce individual differences in performance due to interpersonal differences in pilling abilities, four storage devices were built (see figure 6.6a) in which the rim bands were hang systematically.

Each device had space for 25 rim bands. Two storage devices were positioned on the leftside of the psycho-motor device and two were positioned on the rightside of the

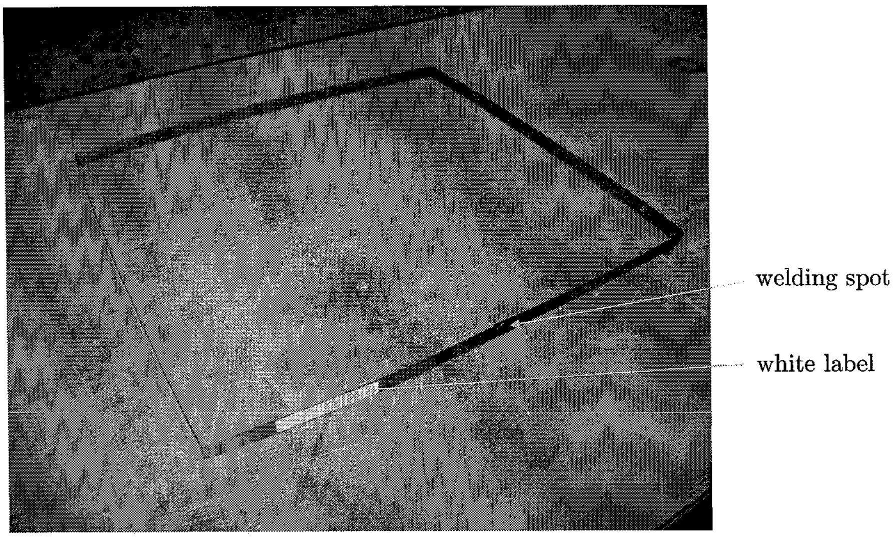
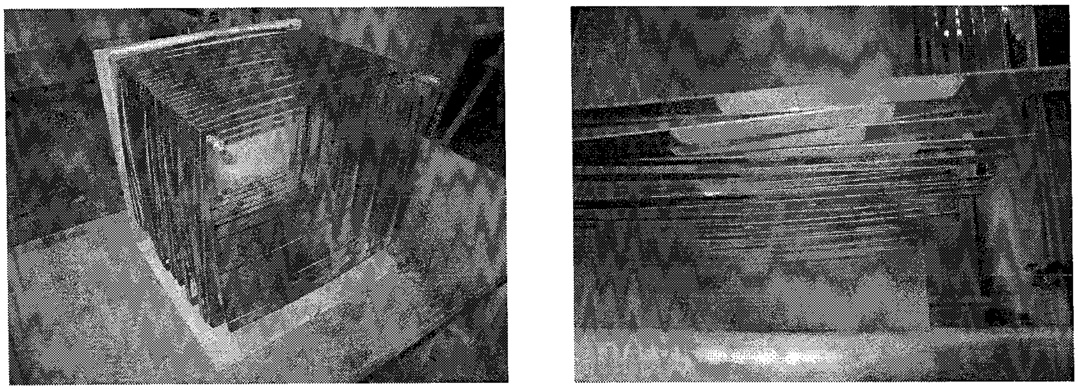


Figure 6.5: Rim Band for the Psycho-Motor Test

psycho-motor test. Half of the storage devices were filled with rim bands, the other half was empty. The bands were hung with the labels pointing to the floor, making it impossible to see their orientation (see figure 6.6b). Almost all labels were positioned on the right side and only single labels were positioned on the left side, thus creating a vigilance test following the definition of Mackworth (1957).



(a) Storage Device for 25 Rim Bands

(b) Positioning of the Rim Band Labels

Figure 6.6: Storage Device for the Psycho-Motor Test

6.3.4 Procedure

The participants had to carry out the following procedure to complete the psycho-motor successfully:

1. The participant takes a rim band from the storage device.

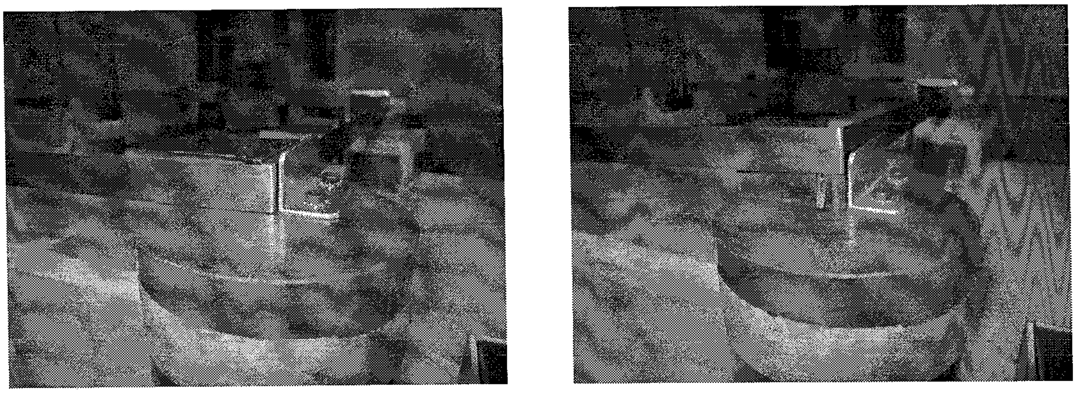
2. The participant positions the rim band in the psycho-motor device.
3. The participant activates the imaginary welding process by pressing the two toggle switches simultaneously.
4. The red LED keeps lighting for 15 seconds.
5. The psycho-motor device determines if the rim band is positioned correctly.
6. The participant releases the toggle switches when the LED stops lighting.
7. The participant hangs the rim band in one of the empty storage devices.

For a continuous work process, four storage devices were needed. The participant took unwelded rim bands from one storage device and, after welding, put them into a storage device for finished rim bands. Once a storage device was filled with welded rim bands, it was taken away by an assistant and the rim bands were repositioned with respect to the white labels, returning to the rest site as "new" unwelded rim bands.

6.3.5 Errors

It was possible to make three kinds of errors during the psycho-motor test:

- Incorrect positioning in the corners of the psycho-motor device (see figure 6.7).
- Incorrect orientation of the rim band with respect to the light barrier (see figure 6.8) indicating the production of a scrap part.
- Early release of one or both of the two toggle switches, i.e., while the red LED still was activated, indicated the interruption of the welding process for safety reasons and, hence, the production of a scrap part as well.

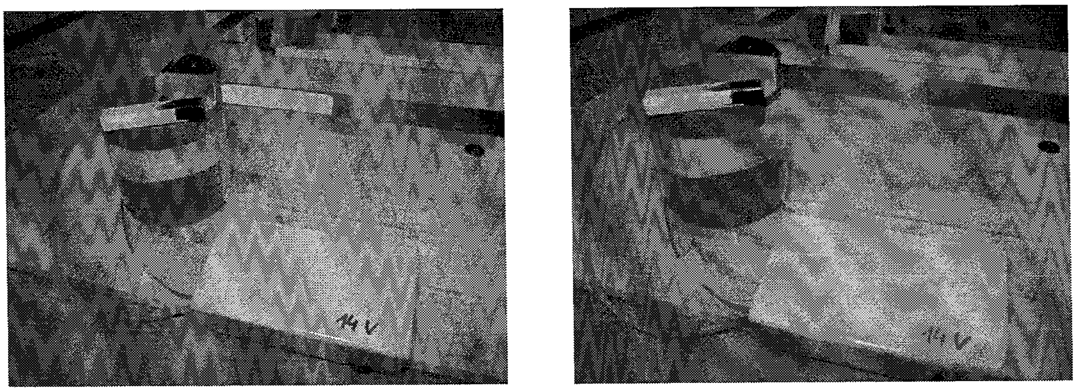


(a) Correct Positioning of the Rim Band

(b) Incorrect Positioning of the Rim Band

Figure 6.7: Sub-Miniature Switches of the Psycho-Motor Device

The according software was implemented in SwitchBoard (IAO 2006) which controlled the system and stored the results automatically.



(a) Correct Orientation of the Rim Band (b) Incorrect Orientation of the Rim Band

Figure 6.8: Infrared Light Barrier of the Psycho-Motor Device

6.4 Divided Attention Test

The dual task of operating the machine producing the lugs while welding rim bands is represented by a computer simulation. The participants had to supervise a simulated semi-automated while conducting the psycho-motor task.

In the simulated production process, manufactured lugs were deposited in a buffer with a maximum storage capacity. The task of the participants was to remove the finished units when this limit was (almost) reached. It is expected that it becomes more difficult to fulfill the divided attention task when sleepiness increases.

6.4.1 User Interface

The simulation was implemented in Macromedia Director MX 2004 (Adobe Systems Inc. 2006). Figure 6.9 shows a screenshot of the lay-out of the user interface. As the experiments were to be conducted with German students, the language of the user interface was German.

The upper part provided information about the status of the machine buffer ("Produzierte Einheiten" [engl.: units produced], "Beschädigte Einheiten" [engl.: units damaged], "Beschädigte Werkzeuge" [engl.: tools damaged] and the "GAU Circle" [Größter Anzunehmender Unfall, engl.: worst case scenario]). The center part contained two buttons ("Pause" and "Holen" [engl. get parts]). The lower part of the screen provided general information ("Zeit" [engl.: time], "Pause", "Punkte" [engl.: points] and the "Status").

The software was installed on a computer with a TFT touchscreen[1] with the simulation filling the whole screen, so that the buttons could be pressed directly on the screen (even by gloved hands). All results were stored automatically.

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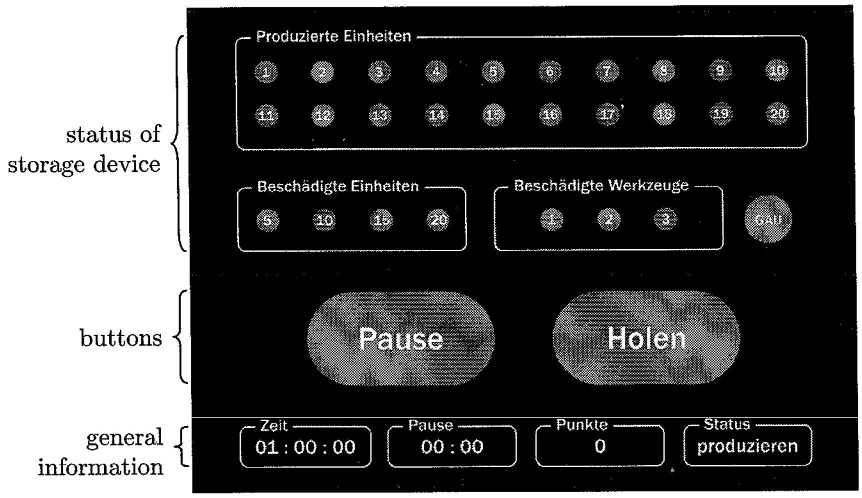
[1] ELO TFT Touchscreen 1926L, size: 19 inch, resolution: 1280x1024 dots (see also figure 6.10)



Zeit: 01 : 00 : 00
Pause: 00 : 00
Punkte: 0
Status: produzieren

Figure 6.9: Screenshot of Lay-Out of the Divided Attention Test

6.4.2 Simulated Work Task

Empty slots in the machine buffer were represented by grey circles in the "Produzierte Einheiten" box. Every ten seconds, a grey circle turned green, indicating the depositing of a lug produced. The buffer could be "emptied" by pressing the "Holen" button. Then all green circles changed back into grey circles again. After a waiting time of 30 seconds, representing the duration of the emptying process, the simulation stated all over again. The delay forced the participants to empty the storage box as late as possible in order to achieve a high production rate.

If the participant did not press the "Holen" button in time, it was assumed that parts in the buffer would be crushed, eventually accumulating and even destroying the production tool head, hence, introducing an error hierarchy. For the same reason, an assumed "GAU" was included, representing personal injury, e.g., by flying parts if the machine was not stopped.

These errors were first represented by yellow circles ("Beschädigte Einheiten"). Every yellow circle represent five destroyed units in the buffer. When four yellow circles were displayed, all units in the buffer were damaged. If the participant did not react, orange circles ("Beschädigte Werkzeuge") indicated the progressive damaging of the tool. Depending on the reaction time, this lead to the necessity to repair the tool and, hence, the simulation was blocked for one, three or five minutes respectively.

If the participant still did not react, the "GAU" circle was lighted and a sound was emitted.

In order to facilitate work breaks, the simulation could be interrupted by pressing the "Pause" button. The text "Pause" then changed from "Pause" to "Weiter" [engl.: continue]. The simulated work process continued, when the "Weiter" button was pressed.

6.4.3 Feedback

During the simulation, the participants received feedback about the amount of time left in the "Zeit" box and the total amount of minutes spent in breaks in the "Pause" box. The total number of units produced was displayed in the "Punkte" box and the status of the semi-automated production process was indicated in the "Status"box, namely: producing, repairing, waiting and taking a break.

6.5 Tests of Attentional Performance

In addition to the factory test, relevant cognitive constructs were measured with a standardized neuro-psychological test battery (Tests of Attention Performance (TAP-M, Zimmermann and Fimm 2005)). The test is computerized (compare to figure 6.10), all results are stored automatically. For reasons on test-time restrictions, only two sub-test could be used: *executive control test* and *alertness test.* Both test included a short training session before the actual measurement.

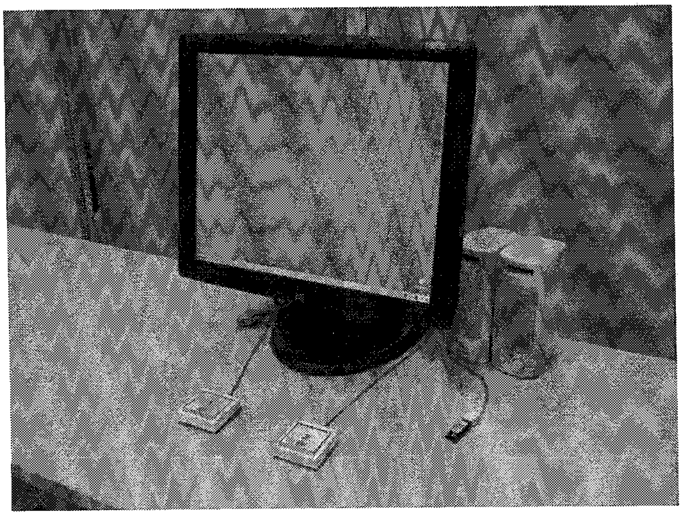


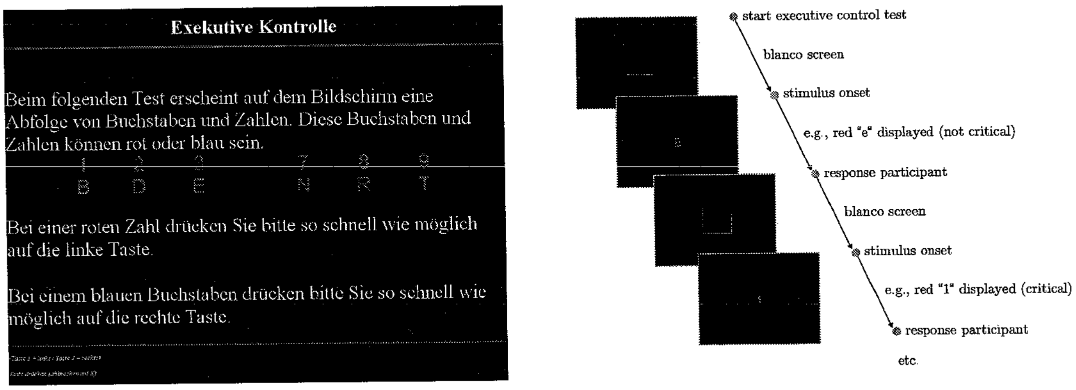
Figure 6.10: Setup for the Alertness Test and the Executive Control Test

6.5.1 Executive Control Test

The executive control test provides a global impression of the mental health status of an individual. It measures aspects of *working memory, divided attention, mental flexibility, selective visual attention, choice reaction and inhibition.* It provides information about the speed/accuracy trade-off on predefined stimulus configurations, which are presented one at a time.

The executive control test generated numbers and letters in the center of a black computer screen, i.e., a red number, a blue number, a red letter or a blue letter could appear. Red numbers and blue letters were critical stimuli. The participant received the instruction to react as fast as possible to these stimuli by pressing the left button for red numbers and the right button for blue letters. If a blue number or a red number appeared (non critical stimuli), the participant was instructed not to press any of the two buttons (compare to figure 6.11).

Relevant parameters were: reaction time, the number of reactions on incorrect stimuli and the number of ignored correct stimuli.



Exekutive Kontrolle

Beim folgenden Test erscheint auf dem Bildschirm eine Abfolge von Buchstaben und Zahlen. Diese Buchstaben und Zahlen können rot oder blau sein.

1 2 3 7 8 9

B D E N R T

Bei einer roten Zahl drücken Sie bitte so schnell wie möglich auf die linke Taste.

Bei einem blauen Buchstaben drücken bitte Sie so schnell wie möglich auf die rechte Taste.

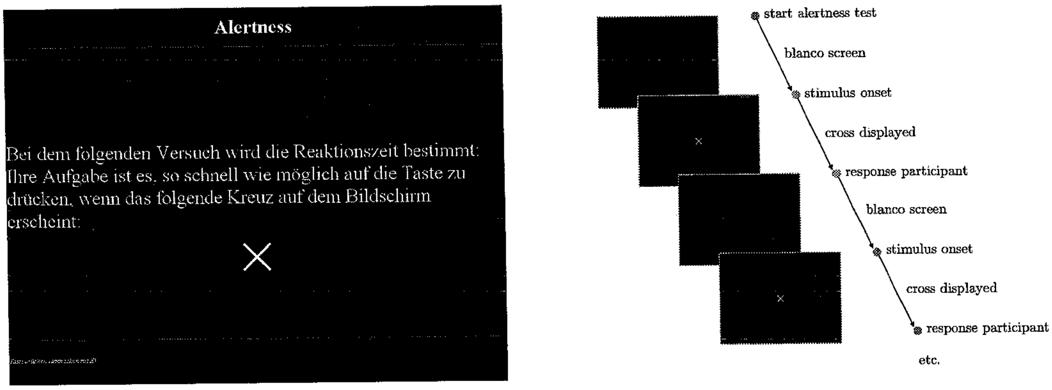
(a) Screenshot of the Instruction Screen

(b) Procedure Test

Figure 6.11: Executive Control Test

6.5.2 Alertness Test

The alertness test examined the tonic alertness of the participants. The task of the participants was to monitor a black computer screen. They received the instruction to press a predefined button as fast as possible every time a white cross appeared. In case of no reaction, the next trial was started automatically after two seconds and the program registered that no response was given (compare to figure 6.12).



Alertness

Bei dem folgenden Versuch wird die Reaktionszeit bestimmt: Ihre Aufgabe ist es, so schnell wie möglich auf die Taste zu drücken, wenn das folgende Kreuz auf dem Bildschirm erscheint:

(a) Screenshot of the Instruction Screen

(b) Procedure Test

Figure 6.12: Alertness Test

7 Method

Four independent variables were defined: *treatment group* (with three levels: no warning strategy, random warning strategy and SENSATION warning strategy), *time of day* (with two levels: evening and morning), *gender* (with two levels: male and female) and *chronotype* (with three levels: morning type, intermediate type and evening type). Additionally, for the TAP-M and the KSS the variable *time of measurement* (with two levels: before and after) was included.

The dependent variable for the factory test was performance. This variable was divided into the number of units correctly produced and number/kind of mistakes made. The dependent variable for the KSS was *self-rated sleepiness* and for the TAP-M it was *reaction time* and *number/kind of mistakes* made.

The experiment was divided into two sub-experiments. One of them was conducted in the evening (from 6:00 p.m. till 8:00 p.m.) with the goal of reducing learn effects as well as to create a baseline measurement. The other sub-experiment was conducted in the morning (from 4:30 a.m. till 8:00 a.m.) in order to maximize the effects of sleepiness. Here, the three groups received different treatments.

The experiment mainly used a between-group-design, the participants were randomly assigned to one of the three treatment groups. The groups were parallelized with respect to gender and chronotype.

The experiments were conducted from 26 September till 30 October 2006. An overview of the experimental design is given in figure 7.1.

7.1 Participants

Although, it would have been desirable to test the HMI-elements of the SENSATION HVMS with professional industrial workers, for cost reasons 24 students (12 male and 12 female) from the University of Stuttgart were acquired. All student had German as native language, their age ranged between 22 and 31 years old (M=25,5 , SD=2,4).

Students who did not follow usual sleep pattern (normal sleep pattern was defined as: 7-9 hours of sleep between 10:00 p.m. and 10:00 a.m.) and students who traveled over more than two time zones within two months before the experiment were excluded because their circadian rhythm might be shifted which could have lead to a difference in sleepiness in comparison to the other students.

The students who participated were free from any physical, mental or sensory impairment (by self-disclosure). Each participant received 100 EUR allowance.

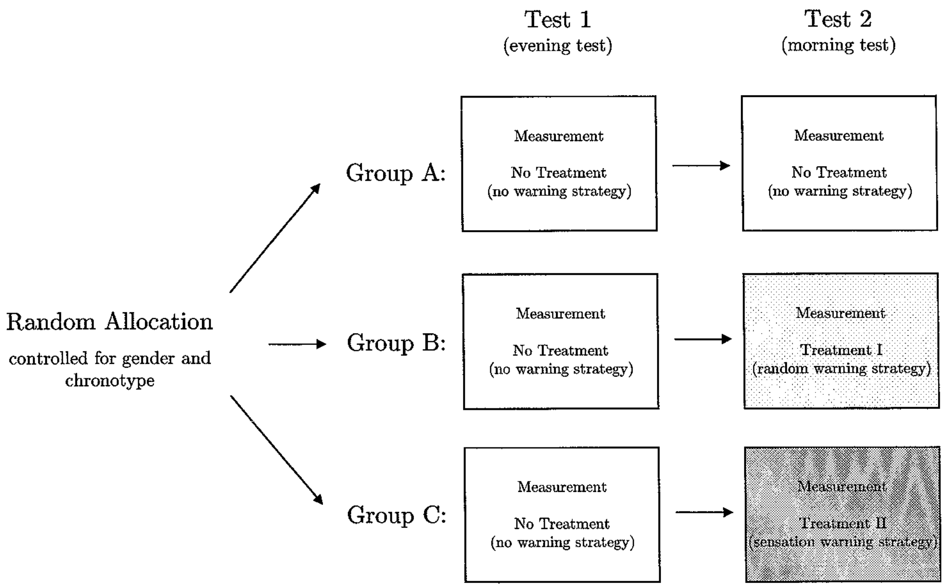


Figure 7.1: Schematical Overview of the Experimental Design

7.2 Laboratory Setting

The experiments were conducted in the ergonomics laboratory at Fraunhofer IAO/IAT University of Stuttgart. There, three areas were created: *a factory setting*, *a control room* and *a rim band repositioning corner*. All areas were separated from each other by movable walls in order to reduce the interaction of participants and staff to a minimum.

7.2.1 Factory Setting

For the psychomotor test, three tables were positioned in a U-shape (see figure 7.2). The middle table was used for the psycho-motor device and the other two tables were used for the four storage devices.

The divided attention test was located on a table located two meters behind the psycho-motor device. Next to the touchscreen, a part of the table was available for the participants to rest during the breaks. This space offered the same kind of relaxation as an ordinary table in an ordinary factory canteen. All tables were 0,85 meter high and restricted the workspace of the participants to a size of 1,5 by 2 meters.

The wires of the HMI-elements of the SENSATION HVMS were hanging from the ceiling in the middle of the factory setting (compare to figure 7.2). It was fixed at the back of the participants on their trousers waistband for pull-relief. From this "central connection point" all other wires were fixed on the body of the participants. This way, the participants could move freely in the factory setting and were only marginally constrained by the system.

Moreover, a video camera was positioned in front of the psycho-motor device. It filmed the participants during the factory test.

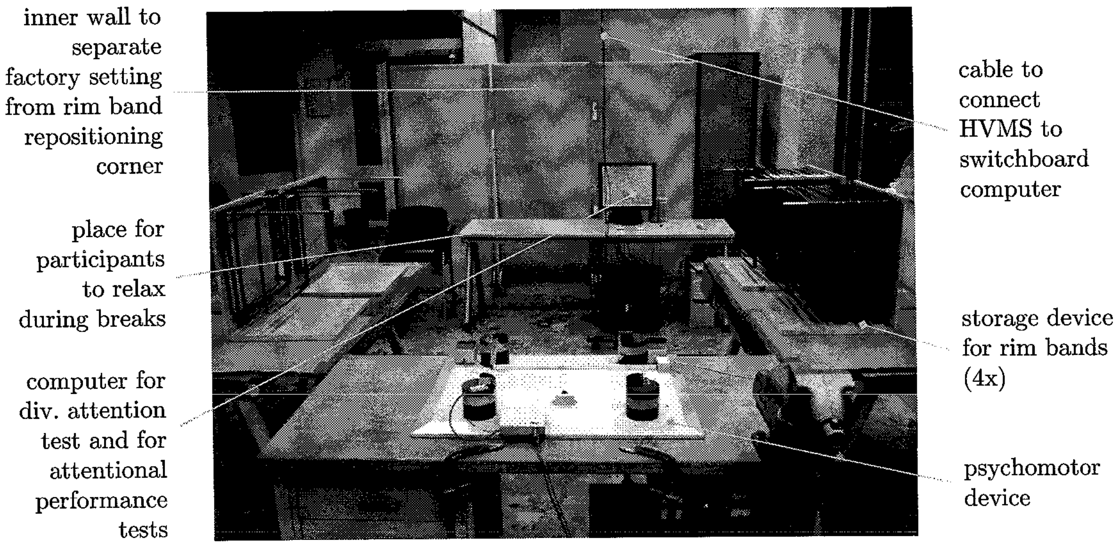


Figure 7.2: Setting of the Factory Test

The temperature, relative humidity, sound intensity and light intensity of the factory setting were controlled in order to ensure comparability of the test results. According measurements took place 15 minutes before each evening/morning test and 15 minutes after each evening/morning test. Table 7.1 shows the mean values of the evening and morning test.

Measurement	evening test	morning test
temperature [°C]	22.6	22,5
relative humidity [%RH]	47.5	48,1
sound [dB]	57.0	57,0
light [LUX]	510	507

Table 7.1: Measurement of Environmental Parameters in the Factory Setting

Moreover, a monotonous sound was produced by a computer sever in the room. The monotonous sound was used to mask the noise produced during the repositioning of rim bands.

7.2.2 Control Room

The test leader was located in the control room, in which the video signal from the factory setting was recorded on a computer and displayed on a 20 inch color television screen. This way, the test leader was enabled to rate sleepiness of the participant and operate the warning strategy of the SENSATION HVMS accordinly[1], which was installed on another computer that also gathered the psycho-motor test data. Figure 7.3 shows the set up of the control room.

Figure 7.3: Setting of the Control Room

7.3 Procedure

The procedure of the experiment is is schematically shown in figure 7.4.

7.3.1 Preparation

Upon registration for the experiment, the participating students had to fill out a questionnaire inquiring demographic and chronobiological data (by means of the standardized German Morningness-Eveningness-Questionnaire, D-MEQ, Griefahn et al. 2001). The questionnaire is included in appendix A. Based on this information the students were matched for gender and chronotype. Then, they were randomly assigned to one of the three treatment groups. All the participants were provided with an information sheet (see appendix D).

Important test parameters were investigated, in two pilot studies. It was found that sleepiness effects were masked by high arousal level of the two test participants. Three major adjustments were made. First, the test time was increased from one and a half to three hours, which is closer to the normal 8 hour shift. Second, the imaginary welding

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[1] As the sensory system of the SENSATION HVMS is still in development and as the aim of this work is to develop and test the HMI-elements of such a system, a Wizard of Oz approach was chosen to test the HMI-elements in which the leader "manually replaces" the sensory system and provides a sleepiness rating to the warning system.

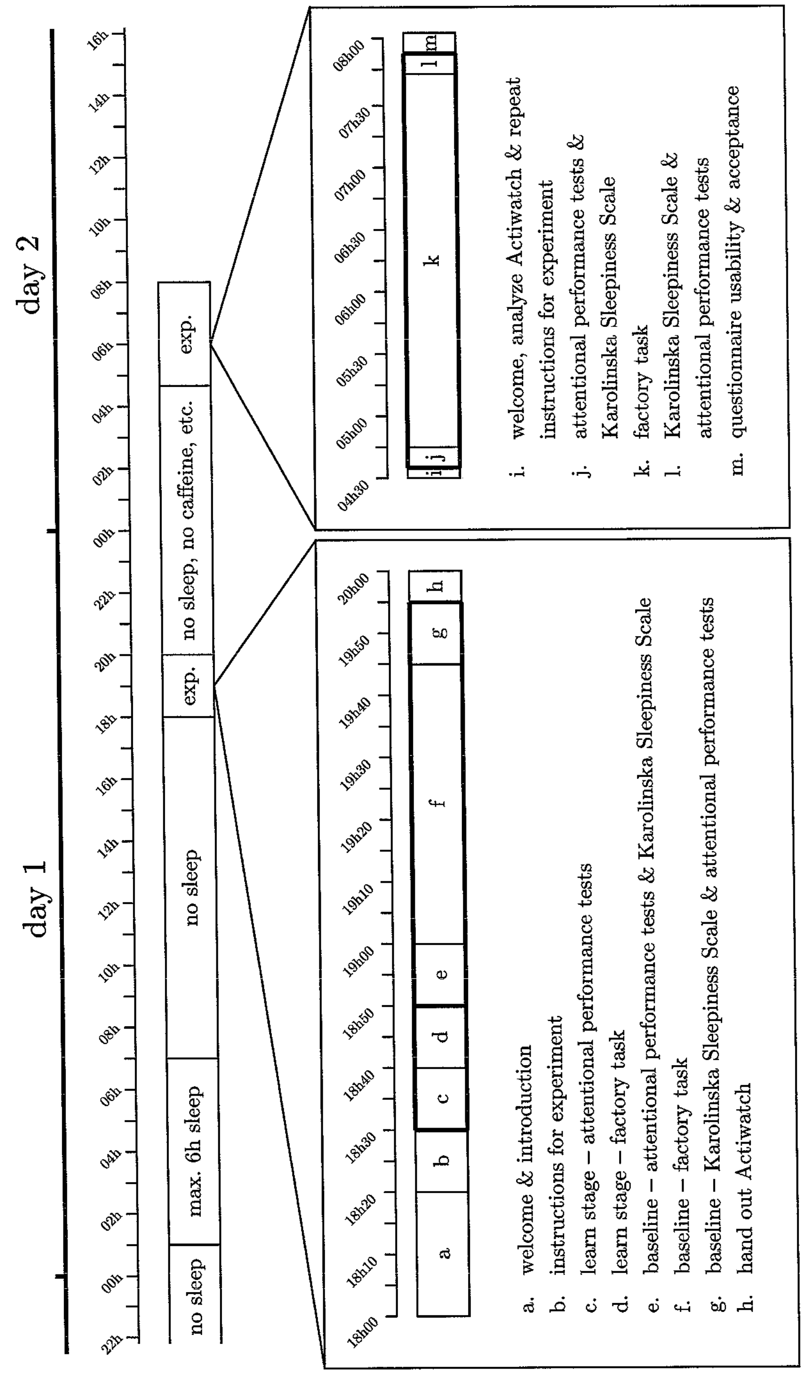

Figure 7.4: Procedure of the Experiment

time was increased 15 seconds which is slightly higher than the original welding time, but enhances the monotony of the task. Third, the preliminarily planned financial bonus for the production of a certain number of units was canceled, because the bonus strongly activated the participants and, hence, reduced the effects of the sleep deprivation. This adjustment is justified by the fact that workers are mostly paid by accord rates. Their aim is not to produce less than the accord level because this way, they would loose money, but also not produce more because of fear of adjustment of their accord level.

7.3.2 Before the Evening Test

Two days before the experiment, the participants underwent particial sleep deprivation. Each participant was instructed to follow a specific sleep–wake schedule. The night before the evening test the participants were not allowed to sleep more than 6 hours. It was recommend to go to bed at 1:00 a.m. and to wake up at 7:00 a.m. at the latest.

7.3.3 Evening Test

The evening test started at 6:00 p.m. and took about 2 hours. First, the participants were re-informed about the test aim and the procedure as well as about potential risks. An informed consent was signed (see appendix E).

The aim of the evening test was twofold. On one hand, the participants should learn the methods and tests used. On the other hand, a baseline measurement was to be conducted. All participants completed the learn phase under the same conditions.

Therefore, the factory test was executed one time for 10 minutes in order to reduce learn effects and a second time for 45 minutes in order to create a baseline level. At both tests, the participants wore the SENSATION HMVS, although it was not activated. Moreover, the participants were not allowed to take a break during the factory test.

The TAP-M tests were administered three times: before the first factory test run and both before and after the secondary test run.

7.3.4 Time Between the Evening Test and the Morning Test

Between the evening test and the morning test, the participants underwent total sleep deprivation. It was checked if the participants really stayed awake by means of actigraphy.

The participants stayed at the test site. During the night they were not allowed to sleep. To pass time, a computer with an Internet connection and a television with a VHS recorder were available. The participants were free to do what ever they liked, however, the consumption of stimulating food and drinks was prohibited. It was recommended to drink water, milk or (fruit) juices.

Usual sanitary facilities were provided.

7.3.5 Morning Test

The morning test started at 4:30 a.m. and took about 3 and a half hours. In general, the baseline measurement was repeated as described above, however, three major differences were implemented: exposure to different treatments, increase in test time and the allowance of breaks.

The three groups were exposed to different treatments. One group received no warning messages. Nevertheless, for reasons of comparability, they had to wear the deactivated SENSATION HVMS. The second group received random warning messages. These did not match their actual level of sleepiness. The last group received the SENSATION warning message. These were timed correctly in accordance with the sleepiness level of the participants.

The participants were allowed to take breaks during the morning test. The no warning group had to rely on themselves in order to start and to stop breaks. The random warning group and the SENSATION warning group got technical assistance to find the optimal moment, although the were free to ignore suggestions of the warning messages. The SENSATION HVMS woke the participants of these two groups 10 minutes after the start of the break.

At the end of the morning experiment, the participants had to fill out a usability and acceptance questionnaire (see appendix F).

8 Results

The software package SPSS 14.0 (SPSS Inc. 2006) and PopTools (CSIRO 2006) were used for the analysis of the recorded data in the experiments. The results are presented in four sections: factory test, Karolinska Sleepiness Scale, tests for attentional performance and additional analysis.

All result reported were statistically tested on a significance level of $p <.05$. The effect sizes (r) were calculated for significant results only, in order get information about the magnitude of the observed effect, i.e., 0 indicating a very small effect and 1 indicating a very large effect. Effect sizes can be compared across different analyses that have measured different variables.

8.1 Factory Test

The psycho-motor test and the divided attention test were analyzed separately, because they tested different underlying cognitive constructs and, hence, a combined score is not meaningful.

Before running the statistical analysis, a performance score P was calculated for the psycho-motor test. This score is based on the ratio between the quantities Q_i of correct products and incorrect products manufactured:

$$\mathrm{P} = \frac{Q_{correct\ units}}{Q_{correct\ units} + Q_{incorrect\ units}} \tag{8.1}$$

The result is a number between zero and one. A low number indicates a low performance and a high number indicates a high performance.

8.1.1 Difference Between Evening and Morning Test

First it was analyzed if there was a difference between the evening and the morning experiment. It should support the view that the total sleep deprivation and early start time had an effect on the result for the factory test. For the psycho-motor test the variables performance, productivity and the amount of errors were analyzed. The amount of errors was calculated by adding the number of incorrect positioned rim bands, incorrect rim band orientations and interrupted welding processes. Because the impact of each error was assumed to be identical, i.e., damage of the rim band, these errors were summarized to a single score.

The divided attention test was analyzed for the variables *performance, productivity, number of damages units.*

To eliminate the performance difference due to duration, the morning score was divided by four because it took four time longer than the evening experiment.

Only the no warning group was included in this analysis, because an increase in performance was expected for the other two groups as a result of the warning intervention, thus:

$$H_0 : \mu_{evening} = \mu_{morning} \tag{8.2}$$

$$H_a : \mu_{evening} < \mu_{morning} \tag{8.3}$$

The descriptive statistics are shown in table 8.1.

Test	Measurement	Time	*M*	*SD*	*N*
psycho-motor	performance	evening	0.93	0.08	8
		morning	0.95	0.06	8
	productivity	evening	79.13	6.58	8
		morning	74.34	6.23	8
	errors	evening	6.63	8.83	8
		morning	4.53	6.61	8
divided attention	performance	evening	0.98	0.02	8
		morning	0.98	0.03	8
	productivity	evening	224.38	7.91	8
		morning	215.78	15.19	8
	damaged units	evening	4.38	4.17	8
		morning	5.16	6.66	8

Table 8.1: Descriptive Statistics for the Differences at the Factory Test Between the Evening and Morning; N=24

For the divided attention test, the number of damaged tools and GAUs caused were not included in the table because these occurred very rarely only. At the evening test no tools were damaged and no GAUs occured. However, at the morning test 4 tools were damaged and 0 GAUs occurred.

The data was non-parametric because the assumption of normality (test of normality by Kolmogorov-Smirnov and Shapiro-Wilk) and homogeneity or/and the assumption of variance (Levene's test) were violated. Therefore, the Wilcoxon signed-rank test was selected. This is the non-parametric equivalent of the dependent t-test and is used for testing differences between groups when there are two conditions (i.e., morning vs. evening) and the same participants have been used in both conditions. The according results are presented in table 8.2.

Only one significant value was found. The participants produced significantly less rim bands in the morning (M=74.34) than at the evening (M=79.13, T=32.00, p <.05).

Test	Measurement	Comparison	T	p	r
psycho-motor	performance	morning vs. evening	26.00	.26	-.28
	productivity	morning vs. evening	32.00	.05	-.49
	errors	morning vs. evening	28.00	.16	-.35
divided attention	performance	morning vs. evening	11.00	.92	-.03
	productivity	morning vs. evening	26.00	.26	-.28
	damaged units	morning vs. evening	10.50	1.00	.00
	damaged tools	morning vs. evening	3.00	.16	-.35

Table 8.2: Results of the Wilcoxon Signed-Rank Test for the Differences at the Factory Test Between the Evening and Morning

8.1.2 Differences Between Treatment Groups at Evening Test

For the psycho-motor test, the variables *performance, productivity and the amount of errors were analyzed.*

For the divided attention test, the variables *performance, productivity, number of damages units* were analyzed. Because none of the tools was damaged and no GAUs occurred at the evening test, these two variables were excluded from this statistical analysis.

No differences between the treatment groups at the evening test were expected, because all the groups worked under the same condition. Therefore, the according statistical (null) hypotheses are:

$$H_0 : \mu_{no\ warning} = \mu_{random\ warning} = \mu_{SENSATION\ warning} \tag{8.4}$$

$$H_a : \text{at least two means are unequal} \tag{8.5}$$

Descriptive statistics of the according data are shown in table 8.3.

The data was non-parametric. Therefore, the data was analyzed using the Kruskal-Wallis test. This is the non-parametric equivalent of the one-way independent ANOVA and is used for testing differences between groups when there are more than two conditions (i.e., no warning strategy, random warning strategy and SENSATION warning strategy) and different participants have been used in all conditions.

No significant results were found. The null-hypothesis could not be rejected. For the psycho-motor test, no significant difference in performance ($H(3)$=0.42, n.s.), productivity ($H(3)$=0.82, n.s.) and number of mistakes made ($H(3)$=0.50, n.s.) could be found. In the same way, for the divided attention test, the variables performance ($H(3)$=2.33, n.s.), productivity ($H(3)$=0.97, n.s.) and amount of damaged units ($H(3)$=2.97, n.s.) did not differ significantly.

Test	Measurement	Treatment Group	M	SD	N
psycho-motor	performance	no warning strategy	0.93	0.08	8
		random warning strategy	0.91	0.11	8
		SENSATION warning strategy	0.91	0.10	8
	productivity	no warning strategy	79.13	6.58	8
		random warning strategy	75.00	9.44	8
		SENSATION warning strategy	77.38	8.33	8
	errors	no warning strategy	6.63	8.83	8
		random warning strategy	7.63	9.50	8
		SENSATION warning strategy	7.63	8.96	8
divided attention	performance	no warning strategy	0.98	0.02	8
		random warning strategy	0.95	0.05	8
		SENSATION warning strategy	0.99	0.02	8
	productivity	no warning strategy	224.38	7.91	8
		random warning strategy	216.63	16.51	8
		SENSATION warning strategy	220.42	7.87	8
	damaged units	no warning strategy	4.38	4.17	8
		random warning strategy	10.00	10.00	8
		SENSATION warning strategy	3.13	5.30	8

Table 8.3: Descriptive Statistics for the Differences at the Factory Test Between the Treatment Groups at the Evening; N=24

8.1.3 Differences Between Treatment Groups at Morning Test

In contrast to the evening experiment, differences were expected to be found between the treatment groups after a night of sleep deprivation. For the psycho-motor test the variables *performance, productivity and amount of errors* were analyzed. For the divided attention test performance, productivity, amount of damaged units, amount of damages tools and number of GAUs were analyzed.

It was expected that the SENSATION warning group would be superior to the no warning group:

$$H_0 : \mu_{SENSATION\ warning} = \mu_{no\ warning} \tag{8.6}$$
$$H_a : \mu_{SENSATION\ warning} > \mu_{no\ warning} \tag{8.7}$$

Moreover, the SENSATION warning group was expected be superior to the random warning group:

$$H_0 : \mu_{SENSATION\ warning} = \mu_{random\ warning} \tag{8.8}$$
$$H_a : \mu_{SENSATION\ warning} > \mu_{random\ warning} \tag{8.9}$$

Finally, the random warning group should be superior the no warning group:

$$H_0 : \mu_{random\ warning} = \mu_{no\ warning} \tag{8.10}$$
$$H_a : \mu_{random\ warning} > \mu_{no\ warning} \tag{8.11}$$

Descriptive statistics of the relevant variables are shown in table 8.4. The number of GAUs occurred are not included in this table. Participants who executed the experiment without have caused a GAU were assigned a GAU-score of zero and participants who caused one GAU were assigned a score of one. Two participants in the random warning group and two participants in the SENSATION warning group caused a GAU. No GAU was caused in the no warning group.

Again, the data was non-parametric. Therefore, the hypothesis were tested with a Mann-Whitney test. This is the non-parametric equivalent of the independent *t*-test and is used for testing diffences between groups when there are two conditions (i.e., SENSATION warning strategy vs. no warning strategy, SENSATION warning strategy vs. random warning strategy and random warning strategy vs. no warning strategy) and different participants have been used in each condition. An overview of the result is given in table 8.5. The number of GAUs was analyzed with a χ^2 test.

No significant results were found for the Mann-Whitney test. At the χ^2 test for the GAUs was not significant either. The SENSATION warning group did not create

Test	Measurement	Treatment Group	*M*	*SD*	*N*
psycho-motor	performance	no warning strategy	0.95	0.06	8
		random warning strategy	0.90	0.09	8
		SENSATION warning strategy	0.87	0.18	8
	productivity	no warning strategy	297.38	24.93	8
		random warning strategy	284.88	47.55	8
		SENSATION warning strategy	289.75	47.61	8
	errors	no warning strategy	18.13	26.47	8
		random warning strategy	32.25	28.26	8
		SENSATION warning strategy	52.13	84.20	8
divided attention	performance	no warning strategy	0.98	0.03	8
		random warning strategy	0.97	0.03	8
		SENSATION warning strategy	0.96	0.05	8
	productivity	no warning strategy	863.13	60.76	8
		random warning strategy	871.75	91.33	8
		SENSATION warning strategy	866.75	64.02	8
	damaged units	no warning strategy	20.63	26.65	8
		random warning strategy	25.00	35.36	8
		SENSATION warning strategy	31.88	45.90	8
	damaged tools	no warning strategy	0.50	0.93	8
		random warning strategy	0.00	0.00	8
		SENSATION warning strategy	0.25	0.71	8

Table 8.4: Descriptive Statistics for the Differences at the Factory Test Between Treatment Groups at the Morning; N=24

Test	Measurement	Comparison	U	p	r
psycho-motor	performance	SENSATION wrn. vs. no wrn.	22.0	.29	-.26
		SENSATION wrn. vs. random wrn.	31.0	.92	-.03
		random wrn. vs. no wrn.	19.0	.17	-.34
	productivity	SENSATION wrn. vs. no wrn.	30.5	.88	-.04
		SENSATION wrn. vs. random wrn.	29.5	.79	-.07
		random wrn. vs. no wrn.	30.0	.84	-.05
	errors	SENSATION wrn. vs. no wrn.	22.5	.32	-.25
		SENSATION wrn. vs. random wrn.	31.0	.92	-.03
		random wrn. vs. no wrn.	21.0	.25	-.29
divided attention	performance	SENSATION wrn. vs. no wrn.	31.0	.91	-.03
		SENSATION wrn. vs. random wrn.	28.0	.67	-.11
		random wrn. vs. no wrn.	32.0	1.00	.00
	productivity	SENSATION wrn. vs. no wrn.	31.0	.92	-.03
		SENSATION wrn. vs. random wrn.	26.0	.53	-.16
		random wrn. vs. no wrn.	26.5	.56	-.14
	damaged units	SENSATION wrn. vs. no wrn.	31.0	.91	-.03
		SENSATION wrn. vs. random wrn.	28.0	.67	-.11
		random wrn. vs. no wrn.	30.5	.87	-.04
	damaged tools	SENSATION wrn. vs. no wrn.	28.0	.54	-.16
		SENSATION wrn. vs. random wrn.	28.0	.32	-.25
		random wrn. vs. no wrn.	24.0	.14	-.37

Table 8.5: Results of the Mann-Whitney Test for the Differences at the Factory Test Between the Treatment Groups at the Morning

significantly more GAUs than the no warning group ($\chi^2(1)=0.57$, n.s.). The same counts for the difference between the SENSATION warning group and the random warning group ($\chi^2(1)=0.33$, n.s.). The random warning group did not create significantly more GAUs than the no warning group either ($\chi^2(1)=0.57$, n.s.).

8.1.4 Characteristics of Participants

Although there were no significant differences between the treatment groups, some variables such as productivity and the amount of errors at the psycho-motor test showed *SDs* that were nearly three times higher in the SENSATION warning group compared to the other two groups (see table: 8.4). Some participants performed much better than the best participants in the no warning group, others performed worse than the worst participants in the no warning group.

It was hypothesized that the effectiveness of the SENSATION HVMS depends on certain characteristics of participants. Therefore, an explorative analysis was conducted with respect to the sub-groups of *gender, age and chronotype.*

8.1.4.1 Effect of Gender

Only the SENSATION treatment group was included in this analysis. The *productivity and amount of errors* at the psycho-motor test and the number of damaged units at the divided attention test had a large *SD* and therefore were investigated.

It was assumed that women use the information of the SENSATION HVMS more sensible than men:

$$H_0 : \mu_{male} = \mu_{female} \qquad (8.12)$$

$$H_a : \mu_{male} > \mu_{female} \qquad (8.13)$$

Descriptive statistics for the variables with respect to gender for the morning test are provided in table 8.6

Test	Measurement	Gender	*M*	*SD*	*N*
psycho-motor	productivity	male	286.00	43.92	4
		female	293.25	57.63	4
	errors	male	30.25	120.22	4
		female	74.00	28.50	4
divided attention	damaged units	male	46.25	57.93	4
		female	17.50	31.75	4

Table 8.6: Descriptive Statistics for the Effect of Gender at the Factory Test; $N=8$

because the data was non-parametric, it was analyzed with a Mann-Whitney test. None of the differences were significant. The productivity at the psycho-motor test did not differ between men (M=286) and women (M=293, U=7.00, n.s.). The same applied to the difference in amount errors made between men (M=30.25) and women (M=74.00, U=8.00, n.s.). The difference in the number of damaged units between men (M=46.25) and woman (M=17.50) did not significantly differ either (U=6.50, n.s.).

8.1.4.2 Effect of Age

The effect of age was analyzed on the same way and with the same variables as it was done for the effects of gender. Therefore, the participants were divided into two categories: from 22 to 24 years old and from 25 to 31 years old.

It was expected that the older participants performed better than the younger participants, because it is assumed that they would show higher compliance with the warning messages:

$$H_0 : \mu_{22-24\,years} = \mu_{25-31\,years} \tag{8.14}$$

$$H_a : \mu_{22-24\,years} > \mu_{25-31\,years} \tag{8.15}$$

The descriptive statistics are listed in table 8.7.

Test	Measurement	Age	M	SD	N
psycho-motor	productivity	22-24 years	285.33	54.97	6
		25-31 years	303.00	16.97	2
	errors	22-24 years	61.50	97.28	6
		25-31 years	24.00	14.14	2
divided attention	damaged units	22-24 years	31.67	50.27	6
		25-31 years	32.50	45.96	2

Table 8.7: Descriptive Statistics for the Effect of Age at the Factory Test; N=8

A Mann-Whitney test was used for the analysis, because the data was non-parametric. The difference in productivity at the psycho-motor test between the 22-24 year old (M=285) and 25-31 year old (M=303) was not significant (U=6.00, n.s.). Likewise, the 25-31 year old participants (M=24.00) did not made significantly more errors at the psycho-motor test than the 22-24 year old participants (M=61.50, U=5.00, n.s.). For the divided attention test the difference in number of damaged units was not significant (U=6.00, n.s.) for 22-24 years old (M=31.67) and 25-31 years old (M=32.50).

8.2 Karolinska Sleepiness Scale

The KSS was applied before and after the evening and morning experiment, i.e., four times. The following analyses were conducted with the respective data.

8.2.1 Difference in Rating Between Evening and Morning Test

First it was analyzed if there was a difference in evaluation between the evening and the morning experiment. It should support the view that the total sleep deprivation and early start time of the experiment had an effect on the internal evaluation of the participants. For this purpose the rating at the beginning of the evening test is compared to the rating at the beginning of the morning test.

An increase in sleepiness is expected resulting from the sleep deprivation.

$$H_0 : \mu_{evening} = \mu_{morning} \tag{8.16}$$

$$H_a : \mu_{evening} < \mu_{morning} \tag{8.17}$$

See table 8.8 for the descriptive statistics.

Measurement	*M*	*SD*	*N*
before evening test	5.04	2.01	24
before morning test	7.33	0.82	24

Table 8.8: Descriptive Statistics for the Differences in Rating at the KSS Between the Evening and Morning; N=24

The data was non-parametric and, therefore, the Wilcoxon signed-rank test was selected. The subjective sleepiness before the morning test (M=7.33), was significantly higher than the one before the evening test (M=5.04, T=2.00, p <.05).

8.2.2 Differences Between Treatment Groups in Evening Test

Here, the change in sleepiness during the evening test is analyzed. Therefore, a difference value of the KSS score measured after the factory test and the one measured before the factory test is computed:

$$\Delta KSS : KSS_{after} - KSS_{before} \tag{8.18}$$

A positive score indicates that the participants became more tired during the test.

For the evening test, no differences between the treatment groups were expected to be found, because all participants worked under the same condition:

$$H_0 : \mu_{no\ warning} = \mu_{random\ warning} = \mu_{SENSATION\ warning} \tag{8.19}$$

$$H_a : \text{at least two means are unequal} \tag{8.20}$$

The according descriptive statistics are shown in table 8.9

Treatment Group	M	SD	N
no warning strategy	-0.13	1.89	8
random warning strategy	-0.38	0.92	8
SENSATION warning strategy	0.38	1.30	8

Table 8.9: Descriptive Statistics for the Differences at the KSS Between the Treatments Groups at the Evening; N=8

The Kruskal-Wallis test was used for the statistical analysis, because the data was non-parametric. No significant differences were found between the treatment groups at the evening experiment ($H(2)$=1.99, n.s.). This confirms the assumption that the participants in the different treatments groups were equal with respect to their subjective sleepiness degradation.

8.2.3 Differences Between Treatment Groups in Morning Test

The change in sleepiness during the morning test is analyzed for the three treatment conditions. A difference value was computed like in the case of the evening experiment. For the morning experiment, differences were expected to be found due to the different warning strategies.

It is expected that the participants in the SENSATION group rated themselves more awake than the participants in the no warning group:

$$H_0 : \mu_{SENSATION\ warning} = \mu_{no\ warning} \tag{8.21}$$

$$H_a : \mu_{SENSATION\ warning} > \mu_{no\ warning} \tag{8.22}$$

In addition, it is expected that the participants in the SENSATION warning group rated themselves more awake than the participants in the random warning group:

$$H_0 : \mu_{SENSATION\ warning} = \mu_{random\ warning} \tag{8.23}$$

$$H_a : \mu_{SENSATION\ warning} > \mu_{random\ warning} \tag{8.24}$$

Moreover, it is expected that the participants in the random warning group rated themselves more awake than the participants in the no warning group:

$$H_0 : \mu_{random\ warning} = \mu_{no\ warning} \tag{8.25}$$

$$H_a : \mu_{random\ warning} > \mu_{no\ warning} \tag{8.26}$$

Treatment Group	*M*	*SD*	*N*
no warning strategy	0.13	0.99	8
random warning strategy	0.50	0.76	8
SENSATION warning strategy	1.13	0.83	8

Table 8.10: Descriptive Statistics for the Difference at the KSS Between the Treatments Groups at the Morning; N=8

The according descriptive statistics are listed in table 8.10

The data was non-parametric and, therefore, analyzed with the Mann-Whitney test. The difference in rating between the SENSATION warning group (M=1.1250) and the no warning group (M=0.13) only curtly missed significance (U=14.50, p=.05). The SENSATION warning group became more sleepy during the experiment than the no warning group. Moreover, no difference was found between the SENSATION warning group (M=1.1250) and the random warning group (M=0.50, U=19.50, n.s.). Finally, the difference in sleepiness rating between the random warning group and the no warning group was not significant either (U=24.50, n.s.).

8.3 Tests for Attentional Performance

Two tests batteries of the test for attentional performance were used at the experiment: *alertness* and *executive control*. The alertness test measured reaction times. The executive control test measured reaction times for correct answers, number of response to incorrect stimuli and number of missing responses to correct stimuli. These last two measures are transformed into the accuracy rate A. It is to be added that the test include 40 critical and 40 not critical stimuli.

$$\mathrm{A} = \frac{Q_{reaction\ to\ correct\ stimuli}}{40} - \frac{Q_{reaction\ to\ incorrect\ stimuli}}{40} \qquad (8.27)$$

The outcome is a rate between zero and one. A low rate means a low accuracy and a high rate means a high accuracy.

8.3.1 Difference in Performance Between Evening and Morning Test

It was analyzed if there was a difference in performance between the evening and the morning experiment. It is expected that attention decrease from evening to morning as a result of the total sleep deprivation. Therefore, the data of all participants at the beginning of the evening experiment was compared to the one at the beginning of the morning experiment.

An increase in sleepiness was expected due to the total sleep deprivation:

$$H_0 : \mu_{evening} = \mu_{morning} \quad (8.28)$$
$$H_a : \mu_{evening} < \mu_{morning} \quad (8.29)$$

The descriptive statistics are shown in figure 8.11

Test	Measurement	M	SD	N
alertness	before evening test	252.96	22.70	24
	before morning test	263.46	24.16	24
executive control	before evening test	561.92	80.80	24
(reation times)	before morning test	537.50	85.75	24
executive control	before evening test	0.95	0.06	24
accuracy rate)	before morning test	0.96	0.06	24

Table 8.11: Descriptive Statistics for the Differences at the TAP-M Between the Treatments Groups at the Morning; N=24

The Wilcoxon Signed-Rank test was used to analyze the data, because it was non-parametric. The difference for the alertness test between the evening (M=252.96) and morning test (M=263.46) only curtly missed significance (T=75.00, p=.055), i.e., the participants reacted slower in the morning than in the evening. The mean reaction times of the participants in the four attention trials were: 562 (SD=80,80), 533 (SD=70,35), 538 (SD=85,75) and 541 (SD=103,43) milliseconds respectively. Thus, it could be assumed that the influence of the learning effect was eliminated first for the measurement after the evening experiment.

However, the finding for the reaction time of the executive control test is not supported by the according accuracy rate as the difference between the respective evening and morning tests were not significant (T=52.00, n.s.).

8.3.2 Differences Between Treatment Groups in Evening Test

Here, the change in reaction time and accuracy during the morning test were analyzed seperately. Therefore, according difference values V_i were computed:

$$\Delta V_i : V_{after} - V_{before} \quad (8.30)$$

No differences were expected to be found, because all treatment groups worked under the same conditions:

$$H_0 : \mu_{no\ warning} = \mu_{random\ warning} = \mu_{SENSATION\ warning} \quad (8.31)$$
$$H_a : \text{at least two means are unequal} \quad (8.32)$$

The descriptive statistics are shown in table 8.12.

Test	Measurement	Treatment Group	*M*	*SD*	*N*
alertness	reaction times	no warn strategy	3.88	22.46	8
		random warn strategy	7.63	14.88	8
		SENSATION warn strategy	2.25	23.96	8
executive control	reaction times	no warn strategy	-36.63	42.28	8
		random warn strategy	-39.25	51.96	8
		SENSATION warn strategy	-9.88	33.19	8
	accuracy rate	no warn strategy	0.01	0.04	8
		random warn strategy	0.02	0.05	8
		SENSATION warn strategy	-0.00	0.03	8

Table 8.12: Descriptive Statistics for the Differences at the TAP-M Between the Treatments Groups at the Evening; N=24

The data was non-parametric. Therefore, the Kruskal-Wallis was test used. None of the result were significant. This confirmed the assumption that all treatment groups were equal.

No significant difference was found for the reaction times in the alertness test ($H(2)$=0.59, n.s.). Neither was a significant difference in reaction times found for the executive control test ($H(2)$=2.26, n.s.). Moreover, the accuracy rate of the three treatment group did not differ significantly ($H(2)$=1.03, n.s.).

8.3.3 Differences Between Treatment Groups in Morning Test

In contrast to the evening experiment, differences in reaction time and accuracy are expected to be found between the treatment groups for the morning test as these were supported by different warning strategies in the factory test.

It was expected that the SENSATION warning group was superior to no warning group:

$$H_0 : \mu_{SENSATION\ warning} = \mu_{no\ warning} \tag{8.33}$$

$$H_a : \mu_{SENSATION\ warning} > \mu_{no\ warning} \tag{8.34}$$

In addition, it was expect that the SENSATION warning group was superior to the random warning group:

$$H_0 : \mu_{SENSATION\ warning} = \mu_{random\ warning} \tag{8.35}$$

$$H_a : \mu_{SENSATION\ warning} > \mu_{random\ warning} \tag{8.36}$$

Moreover, it was expect that the random warning group is superior to the no warning group:

$$H_0 \quad : \quad \mu_{random\,warning} = \mu_{no\,warning} \tag{8.37}$$
$$H_a \quad : \quad \mu_{random\,warning} > \mu_{no\,warning} \tag{8.38}$$

The according descriptive statistics are shown in table 8.13.

Test	Measurement	Treatment Group	*M*	*SD*	*N*
alertness	reaction times	no warning strategy	0.38	39.70	8
		random warning strategy	18.13	32.74	8
		SENSATION warning strategy	15.57	12.33	8
executive control	reaction times	no warning strategy	20.25	23.65	8
		random warning strategy	18.88	43.25	8
		SENSATION warning strategy	-46.29	119.49	8
	accuracy rate	no warning strategy	-0.04	0.07	8
		random warning strategy	-0.02	0.07	8
		SENSATION warning strategy	-0.10	0.11	8

Table 8.13: Descriptive Statistics for the Differences at the TAP-M Between the Treatments Groups at the Morning; N=24

Because the data was non-parametric, the Mann-Whitney test was used for the analysis. An overview of the results is given in table 8.14

Test	Measurement	Comparison	*U*	*p*	*r*
alertness	reaction time	SENSATION wrn. vs. no wrn.	10.00	.04	-.52
		SENSATION wrn. vs. random wrn.	25.00	.73	-.09
		random wrn. vs. no wrn.	21.00	.25	-.29
executive control	reaction time	SENSATION wrn. vs. no wrn.	18.50	.27	-.28
		SENSATION wrn. vs. random wrn.	22.00	.49	-.17
		random wrn. vs. no wrn.	29.00	.75	-.08
	accuracy rate	SENSATION wrn. vs. no wrn.	19.50	.32	-.25
		SENSATION wrn. vs. random wrn.	13.00	.08	-.44
		random wrn. vs. no wrn.	25.00	.43	-.20

Table 8.14: Result of the Mann-Whitney test for the Differences at the TAP-M Between the Treatments Groups at the Morning

Only one result was significant. The level of alertness of the no warning group (M=0.375) decreased less over time than that of the SENSATION warning group (M=15.57, U=10.00, p <.05).

8.4 Additional Analysis

In this section, the difference in level of sleepiness as determined by the rater and the duration of breaks made by the participants is analyzed for the morning experiment.

The level of sleepiness was defined on a scale from 0 to 2 (0=awake, 1=moderate sleepy and 2=very sleepy). The duration of the breaks was measured in seconds. Because several breaks could be made, the duration of all breaks were summed up.

To analyze if there were differences between the treatment groups, the following hypothesis was tested:

$$H_0 : \mu_{no\ warning} = \mu_{random\ warning} = \mu_{SENSATION\ warning} \tag{8.39}$$

$$H_a : \text{at least two means are unequal} \tag{8.40}$$

An overview of the descriptive statistics are given in table 8.15.

Measurement	Treatment Group	M	SD	N
sleepiness	no warning strategy	0.63	0.92	8
	random warning strategy	0.63	0.74	8
	SENSATION warning strategy	0.63	0.71	8
duration of breaks	no warning strategy	591.38	475.48	8
	random warning strategy	635.63	678.01	8
	SENSATION warning strategy	677.75	376.37	8

Table 8.15: Descriptive Statistics for the Differences Between the Treatments Groups at the Morning; N=24

The data was non-parametric. Therefore, Two Kruskal-Wallis test were used analyze the difference between the groups.

No significant difference for sleepiness (as determined by the rated) was found ($H(2)$=0.123, n.s.). In the same way, no difference in amount of breaks between the three groups was detected ($H(2)$=0.781, n.s.).

9 Discussion

For all dependent variables, no significant differences were found between the treatment groups for the baseline measurement (i.e., evening test). It can be concluded that there was no systematic difference between the treatment groups which is a pre-requisite for the direct comparability of the actual measurements.

The participants rated themselves significantly more sleepy in the morning experiment than they did at the evening experiment, i.e., the night of total sleep deprivation had the desired effect. It made the participant sleepy, so that the SENSATION HVMS could be tested meaningfully.

The main test of the experiment, i.e., the factory test, showed that, without warning intervention, significantly less rim bands were produced in the morning than in the evening. Moreover, more severe errors were made, but no difference could be found for "small" errors such as the fail-production of rim bands. It can be concluded that the experimental task was well designed as it reproduced the decrease in performance due to sleepiness. It is to be noted that divided attention was more impaired than selective attention.

The participants showed a reduced attention level in the morning compared to their results in the evening (both times with respect to the measurement before the factory test, i.e., without specific intervention). This finding was expected and indicates that the overall test setup worked out well.

However, no other significant differences could be found for the TAP-M tests between the evening and the morning experiment (but one—see below). But, as sleepiness reduces attention and the abilities with respect to alertness related constructs (such as the one examined by the executive control test), the participants should perform worse in the morning compared to the evening. This finding can be explained by learning effects leading to a relatively better performance in the morning which is counteracted by the effects of sleepiness, resulting in no significant difference in the data measured. It is known that neuro-psychological test tools as TAP-M show a steep learning curve in their users. Therefore, they need to be trained before doing the actual measurements. Although the test design induced learning sessions in order to reduce these effects to a minimum, it is likely that more learning of the tests would have been necessary for a reliable measurement.

This argument is supported by the fact that, in the executive control test, participants even reacted significantly faster to the stimuli in the morning test than in the evening test, due to a learning effect, which seemed to become stable for the measurement after the evening test only.

An alternative would have been to compare the results of the measurements *after* the factory test. This was rejected as an interference of the different treatment of the groups could not be ruled out.

Overall, it can be concluded that the experimental set-up itself worked in the way designed and, thus, the measurement data can be analyzed without further retention.

9.1 Discussion of the Treatment Group Comparison for the Morning Experiment

The effect of the SENSATION HVMS was not large. Only a few significant results have been found.

For the factory test as the main test criterion of the validation study, the relatively large spread in variation of the results of the SENSATION warning group compared to the other two groups was striking. Some participants in the SENSATION warning group performed better than the best participants in the no warning group and some performed worse than the worst performing participant in the no warning group. This difference indicates that the SENSATION HVMS is helpful for some persons and disturbing for others. It could have helped some participants to make accurate decisions when to take a break. However, by it mere presence, it could have also reminded the participants of the two other groups that they are sleepy. Unfortunately, no specific cause for this variation, such as gender or age, could be found. A hint is given though, as the older group made significantly more errors in the psycho-motor test than the younger group.

Although, the data was not significant, a tendency was observed that indicated that the SENSATION warning group rated themselves more sleepy than the no warning group. Probably, when someone is continuously reminded that he/she is sleepy, it is very likely that this person is more conscious of his/her alertness state and rates him-/herself more sleepy at the KSS. This support the opinion, that the SENSATION HVMS can increase safety by making its user more aware of their true alertness state, thus causing them to take according safety measures when necessary.

No significant differences between the end and the beginning of the morning test were found with respect to the TAP-M, but in one case. However, the SENSATION warning group performed slightly better than the no warning group, giving a hint about the usefulness of such system.

The additional test showed neither significant differences for the maximum level of sleepiness nor for the duration of the breaks. However, the SENSATION warning group had the longest duration of breaks and the no warning group the least. Hence, it can be assumed the SENSATION HVMS stimulate to take a break.

9.2 Observation of Participants at the Factory Test

During the experiment the participants were observed by the test leader. Unusual behavior and decisions was recorded and discussed in a short interview after the factory test.

The effects of sleepiness were different for each participant. Some showed many signs of sleepiness whereas others were able to hide these signs. Contrary to the SENSATION warning group, the random warning group received warn messages that were not related to their actual sleepiness state. This caused an inner conflict, because timing of the message did not match with their personal judgment of their level of sleepiness. As a result, the participants in the random warning group often ignored the messages and kept working. Moreover, they reported that the messages were experienced as annoying. Thus, it can be concluded that the effectiveness of the warning messages depended on the coherence of the warning with the subjective sleepiness evaluation. Therefore, a proper timing of the warning messages seems to be crucial in order to reach high compliance of the user with respect to the warning.

The participants did set goals during the morning test. On forehand, many decided to take a break somewhere in the middle of the experiment. The willingness to take a break decreased when the end of the test was approaching or when they already took a break previously. In this case, the duration of the breaks was reduced, when taken at all. Further, some participants first wanted to take a break, when a storage device of the psycho-motor test was emptied or when a symbolic number (e.g., 50, 100, 150, etc.) of parts produced was reached at the divided attention test.

Moreover, it was observed that some participants had the ability to plan their breaks at suitable moments. Without technical assistance, they were able to detect accurately when they were getting sleepy while others did not had this ability and interrupted their task too early (which is inefficient) or kept working too long (which represents an increased risk on an error).

The breaks were used differently. Some participants tried to make a short nap, while others just sat down and relaxed and drunk water. Most participants removed the ear plugs of the SENSATION HVMS at the break. They were experienced as annoying, especially by those who wanted to take a nap. In these cases, the earplug were being experienced as being annoying and, hence, could be a source of arousal.

It can be concluded that many individuals do not know when and how to take a break most efficiently. For them, the SENSATION HVMS could be a helpful device.

The interaction of the participants and the SENSATION HVMS was always flawless. No clear tactile or auditory feedback was given by the confirmation button when pressed. Therefore, the button was often pressed a couple of times, although the feedback has already been received by the system. Clearly, a tactile and/or auditory feedback to the user is necessary.

Another problem occurred when the "sleepy" mode was entered. Normally, after the transmission of the warning message, the participant had a few seconds time to press the confirmation button. If no direct reaction followed, the SENSATION HMVS assumed that the participant fell asleep and repeated the message or went into imminent mode. However, in practice the participant could not always confirm the warning message directly. For instance, when the participant just activated the welding procedure at the psycho-motor device, he/she was not allowed to release the buttons for fifteen seconds. But in this time, the SENSATION HVMS incorrectly assumed that the participant was asleep. In conclusion, it is important that the time needed to press the confirmation button is adjustable.

The texts of the warning messages were directly understood by the participants and the functions of the SENSATION HVMS could be easily remembered.

The psycho-motor device suffered from a few imperfections. When at least one of the two buttons was released too early, the LED (representing the welding process) did not went out automatically, but kept lighting until the fifteen seconds welding time were over. This is in contradiction to the original welding process, which, for safety reasons, would be interrupted immediately in case of one button released. In order to compensate for this, the participants were instructed to remove the incorrectly welded rim band and position a new one. Then, when the red LED went out, they were allowed to press both buttons again.

Moreover, it should be noted that three times during the experiments, a malfunction of the red LED occurred. Two times the voltage of the power supply dropped and had to be correct during the test. However, the resulting intervention was minimal and can be neglected. A more serious malfunction occurred once, when the voltage in the LED-circuit was too high. The LED broke down about 45 minutes before the end of the morning experiment. The test continued with a minimal delay, but feedback about the welding process was given on a computer screen. It is assumed that the resulting disturbances of the experiment, overall, can be neglected. However, it is possible that additional arousal was created.

9.3 Usability and Acceptance Questionnaire

In this section the results of the usability and acceptance questionnaire are shown and discussed.

9.3.1 Usability

Most participants found the SENSATION HVMS easy to use (12/13). The functions were easy to learn (12/14) and were easy to remember (12/13). However, according to eleven out of fifteen participants, the SENSATION HVMS did not help or even disturb during the test.

The status indicator of the wristwatch-like device was easy to understand (12/15). More than half of the participants were satisfied with the levels of sleepiness displayed by the status indicator (11/15). Opinions about the location of the status indicator were mixed. Many were satisfied (7/15), some others were dissatisfied (2/15). The number and size of LED was rated as sufficient (12/14).

More than half of the participants were satisfied with the positions (9/14) and the sizes (11/13) of the buttons. Reactions about the feedback and the required operation force of the buttons were mixed. Five out of thirteen found the required force needed to operate the buttons acceptable. However, three out of thirteen complained, because the work gloves made it difficult to press to button it correctly. Three out of thirteen participants were satisfied about the feedback while five of out of thirteen participants were dissatisfied. The last group declared that did not know when the button was pressed correctly. This supports the above finding about feedback of the buttons.

All participants found it easy to understand the speech messages (13/13). The content was clear (12/13) and easy to remember (12/13). Two out of six participants in the random warning group declared that they followed the warning message(s). In the SENSATION warning group five out of seven participants declared that they have followed the instructions. A high compliance to the warnings of the SENSATION HVMS can be deducted.

The factory task did not become easier or more difficult when the warning strategy was prominent (4/11). Eight out of eleven participants found it easier to stay awake when VMM was activated. This underlines the usefulness of such a system in order to help sleepy people safely stopping their dangerous work taks.

Some individuals were satisfied with the place of attachment of the vibrotactile device (3/11), others were not satisfied (3/11). The largest group was undecided (5/11).

Half of the participants experienced their mobility impaired by the SENSATION HVMS (9/18). Clear advantages of a wireless system can be deducted.

The participants were undecided about the influences of design (10/19), size (10/20) and many (12/20) participants were satisfied with the weight of the SENSATION HVMS.

9.3.2 Acceptance

No participant refused to use the SENSATION HVMS at all (0/24). Consequently, they are most likely to use a SENSATION HVMS when it warns them in case of extreme sleepiness (23/24). This is supported by the finding that half of the participants would like to get insight in real time data about their own sleepiness level (12/24). Only a few (5/24) would be willing to provide the employer with real time data of their sleepiness level. However, when sleepiness data was revealed on a group level (one value for a group of persons), most participants would be willing to share their data (18/23).

9.3.3 Motivation

A fourth of the participants (6/22) had a high productivity as their main goal, another fourth of the participants had a low number of errors as goal. The others (11/22) tried to find a combination between both, a high productivity and a low number of errors.

9.4 Conclusions

The experimental setup worked as planned, all pre-requisites could be fulfilled. However, the research question and the corresponding hypotheses could not be confirmed by this experiment. The SENSATION warning group did not perform significantly better than the no warning group. Likewise did the random warning group not perform better than the no warning group and the SENSATION warning group did not perform significantly better than the random warning group.

An increase in sleepiness often has a negative influence on the quality of the work of an industrial worker. The experiment indicates that the use of the SENSATION HVMS could solve this problem for some persons. However, it should be clear that such technical assistance should only be provided when no other countermeasures against sleepiness are possible. An industrial worker that struggles with the symptoms of sleepiness during his/her night shift should first discuss with his/her boss which countermeasures could be taken, like the placement into an other shift or try to introduce more variation in his/her task. If there is no room for adjustments, then the SENSATION HVMS could be a good alternative. It should be noted that even when using the SENSATION HVMS it is possible to make mistake.

In other fields of application which include more monotonous task with less physical activation such as the transportation sector, the effectiveness of the SENSATION HVMS is probably higher. Due to the amount of movement of the psycho-motor tasks, physical activation could (partly) have counteracted the effects of the sleep deprivation. Perhaps, should be concluded that the SENSATION HVMS is not suitable for all kinds of tasks.

9.5 Outlook on Further Research

The experiment conducted in this work had a high face validity. The experiment closely mapped a typical task on an industrial worker. Still, only minor direct improvements of safety and performance could be observed. This finding might be explained by the constant physical activation and, thus, arousal of the participants. It is concluded that, for these tasks, the main danger is not a constant degradation of performance, but more a general degradation of alertness, which might, e.g., lead to accidents such as falling down a stair or not seeing a fork lift passing by. These situations could not be tested in the laboratory. Thus, it would be wishful to test the SENSATION HVMS in a real life setting over a long period of time.

Moreover, three hours of testing seems to be too short. Most participants planned to take one break in the middle of the test on forehand. This was also the part of the experiment at which most participants got sleepy, resulting in a comparable break behavior for all groups. However, actual workers fulfill the same task eight hours and this makes it more difficult to plan optimal breaks. Here, a SENSATION presumably could momentously increase the breaking efficiency and, thus, increase safety and help maintaining the personal performance level.

Furthermore, the SENSATION HVMS should be constructed in a way that the participants forget that they are wearing the device. The cables and earplugs were disturbing elements. It cannot be ruled out that these disturbing elements caused an experimenter effect as the participants were frequently reminded that their level of sleepiness was being measured. Especially for the no warning group this lead to an undesirable effect. Perhaps they made more breaks than that they normally would have done. For this reason a less intrusive version of the SENSATION HVMS should be tested in further research. For the system used in this work, it is already planned to implement a wireless version solving the problem mentioned.

Moreover, a videocamera was located in front of the psycho-motor device to enable the rater to observe facial expressions of the participants. The camera might frequently have reminded the participants that they were being observed/recorded. It cannot be excluded that the participants wanted to avoid being observed/recorded while showing extreme signs of sleepiness causing them to decide to take their breaks a bit earlier than they normally would have done.

The participants were allowed to take breaks during the morning test under the condition that each break would take ten minutes maximum. For participants who wanted to make a nap, ten minutes was a bit short as the participants needed some time to reach a comfortable sleeping position. The remaining time was often too short to get into the first stage of sleep (muscle relaxation) which recovers the participant. Therefore, the break time needs to be increased, e.g., to about fifteen or twenty minutes. Moreover, the adjustment of the break time according to the actual sleep stage of the user could improve the system and should be investigated in further research.

The SENSATION HVMS has been tested for a repetitive positioning task, which is a typical task of an industrial worker. It could also be interesting to test the SENSATION HVMS for other kinds of industrial tasks, like operating a milling machine. The task is not as monotonous as the positioning task, but it is much more dangerous because of to the rotating cutter or endmill. It is more difficult to protect the industrial worker against injuries and a single mistake can lead to severe accidents.

Further should acceptance issues be investigated. It is important to know under which conditions the participants would like to use the SENSATION HVMS. Their privacy could be violated, when the data is sheared with other persons. In the same way, the SENSATION HVMS could be used to control the status of single workers, which is represented in the concern of the participants about giving their sleepiness data to a potential employer. Before introducing such system to real work systems, these ethical issues need to be considered and discussed.

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Appendix

The following documents can be found in the appendix:

A. Fragenbogen zum Chronotyp

- Englisch: German Morningness-Eveningness-Questionnaire
- Number of pages: 5
- Source: Horne and Östberg, 1976

B. KSS

- Englisch: Karolinska Sleepiness Scale
- Number of pages: 1
- Source: Åkerstedt and Gillberg, 1990

C. Wierwille's Scale (Desciption of Drowsiness Continuum)

- Number of pages: 2
- Source: Wierwille and Ellsworth, 1994

D. Informationsblatt für Schläfrigkeits-Experiment

- Englisch: Information Sheet
- Number of pages: 2

E. Einverständniserklärung

- Englisch: Informed Consent
- Number of pages: 1

F. Gebrauchstauglichkeit und Akzeptanz

- Englisch: Usability and Acceptance Questionnaire
- Number of pages: 5

Fragebogen zum Chronotyp

Dieses Dokument hat als Ziel auf zu zeigen am welcher Uhrzeit Sie am produktivsten sind.

Anweisungen:

- Bitte lesen Sie jede Frage sorgfältig durch, bevor Sie antworten.
- Beantworten Sie bitte alle Fragen, auch dann wenn Sie sich bei einer Frage unsicher sind.
- Beantworten Sie die Fragen in der vorgegebenen Reihenfolge.
- Beantworten Sie die Fragen so schnell wie möglich. Es sind die ersten Reaktionen auf die Fragen, die uns mehr interessieren als eine lange überlegte Antwort.
- Beantworten Sie jede Frage ehrlich. Es gibt keine richtige oder falsche Antwort.

---

1. Wenn es nur nach Ihrem eigenen Wohlbefinden ginge und Sie Ihren Tag völlig frei einteilen könnten, wann würden Sie dann aufstehen ?

○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
5		6		7		8		9		10		11		12

2. Wenn es nur nach Ihrem eigenen Wohlbefinden ginge und Sie Ihren Abend völlig frei gestalten könnten, wann würden Sie dann zu Bett gehen ?

○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
20		21		22		23		24		1		2		3

3. Wie sehr sind Sie von Ihrem Wecker abhängig, wenn Sie morgens zu einer bestimmten Zeit aufstehen müssen ?

○ Überhaupt nicht abhängig
○ Etwas abhängig
○ Ziemlich abhängig
○ Sehr abhängig

4. Wie leicht fällt es Ihnen üblicherweise morgens aufzustehen ?
    - ○ Überhaupt nicht leicht
    - ○ Nicht sehr leicht
    - ○ Ziemlich leicht
    - ○ Sehr leicht

5. Wie wach fühlen Sie sich morgens in der ersten halben Stunde nach dem Aufwachen ?
    - ○ Überhaupt nicht wach
    - ○ Ein bisschen wach
    - ○ Ziemlich wach
    - ○ Sehr wach

6. Wie ist Ihr Appetit in der ersten halben Stunde nach dem Aufwachen ?
    - ○ Sehr gering
    - ○ Ziemlich gering
    - ○ Ziemlich gut
    - ○ Sehr gut

7. Wie müde fühlen Sie sich morgens in der ersten halben Stunde nach dem Aufwachen ?
    - ○ Sehr müde
    - ○ Ziemlich müde
    - ○ Ziemlich frisch
    - ○ Sehr frisch

8. Wenn Sie am folgenden Tag keinerlei Verpflichtungen haben, wann gehen Sie dann - verglichen mit Ihrer üblichen Schlafenszeit - zu Bett ?
    - ○ Selten oder nie später
    - ○ Weniger als eine Stunde später
    - ○ 1 - 2 Stunden später
    - ○ Mehr als 2 Stunden später

9. Sie haben beschlossen, sich körperlich zu betätigen. Ein Freund rät Ihnen, zweimal wöchentlich eine Stunde zu trainieren; für ihn sei die beste Zeit zwischen 7 und 8 Uhr. Ausgehend von Ihrem eigenen Wohlbefinden, wie schätzen Sie Ihre Leistungsfähigkeit zu dieser Zeit ein ?

○ Ich wäre gut in Form
○ Ich wäre ziemlich in Form
○ Es wäre ziemlich schwierig für mich
○ Es wäre sehr schwierig für mich

10. Um wieviel Uhr werden Sie abends müde und haben das Bedürfnis, schlafen zu gehen ?

○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
20		21		22		23		24		1		2		3

11. Sie möchten für einen zweistündigen Test, von dem Sie wissen, dass er mental sehr beansprucht, in Bestform sein. Wenn es nur nach Ihrem eigenen Wohlbefinden ginge und wenn Sie Ihren Tag völlig frei einteilen könnten, welchen der vier Test-Zeiträume würden Sie wählen ?

○ 8 - 10 Uhr
○ 11 - 13 Uhr
○ 15 - 17 Uhr
○ 19 - 21 Uhr

12. Wenn Sie um 23 Uhr zu Bett gehen sollten, wie müde wären Sie dann?

○ Überhaupt nicht müde
○ Etwas müde
○ Ziemlich müde
○ Sehr müde

13. Aus irgendeinem Grund sind Sie einige Stunden später als gewöhnlich zu Bett gegangen. Es besteht jedoch keine Notwendigkeit, am nächsten Morgen zu einer bestimmten Zeit aufzustehen. Welcher der folgenden Fälle wird bei Ihnen am ehesten eintreten ?

○ Ich werde zur üblichen Zeit wach und schlafe nicht wieder ein
○ Ich werde zur üblichen Zeit wach und döse danach noch ein wenig
○ Ich werde zur üblichen Zeit wach, schlafe dann aber wieder ein
○ Ich wache erst später als üblich auf

19. Man spricht bei Menschen von 'Morgen-' und 'Abendtypen'. Zu welchem der folgenden Typen zählen Sie sich ?

- ○ Eindeutig 'Morgentyp'
- ○ Eher 'Morgen-' als 'Abendtyp'
- ○ Eher 'Abend-' als 'Morgentyp'
- ○ Eindeutig 'Abendtyp'

Haben Sie alle Fragen beantwortet?

Wenn ja, bitte senden Sie mir dann Ihre Antworten durch Klick auf folgende Button.

Per E-Mail senden

Bitte stellen Sie sicher, daß Sie eine funktionierende Verbindung zum Internet haben! Bei Problemen mit dem Dataversand versuchen Sie zunächst, die Datendatei zu speichern und diese als Attachment mit einer normalen Mail zu senden (nach Klick auf obigen Button, "Sonstiges" auswählen und der Anleitung folgen). Sie können das Formular aber auch ausdrucken und mir zufaxen, oder es am Empfang des IAO abgeben.

Vielen Dank!

Pernel van den Hurk

Email: pernel.hurk@iao.fraunhofer.de
Tel: 0711/970-2126

KSS

Bitte bewerten Sie Ihre Müdigkeit, indem Sie eine entsprechende Zahl zwischen 1 und 9 angeben. Benützen Sie auch die Zwischenabstufungen:

---

1 = sehr wach
2
3 = wach - normaler Level
4
5 = weder wach noch müde
6
7 = müde, aber keine Probleme wach zu bleiben
8
9 = sehr müde, große Probleme wach zu bleiben, mit dem Schlaf kämpfend

---

Datum: __.__.2006 Uhrzeit: __:__

Desciption of Drowsiness Continuum (in German)

Die folgenden Ausführungen zu den 4(!) vom Zustand des Wachseins (auf der Skala "gar nicht müde") abweichenden Wachheitsgraden des Probanden sollen Ihnen mittels genauerer Verhaltens-Charakteristika die Zustands-Beurteilung und -Entscheidung bei der Verhaltensbeobachtung erleichtern. Es sei erneut darauf hingewiesen, dass der Übergang zwischen „gar nicht schläfrig“ und „extrem schläfrig“ kontinuierlich verläuft. Die unten beschriebenen Merkmale markieren also die einzelnen Skalen-Anker; sie treten aber entsprechend auch in den Übergangsstufen auf, da die bezeichneten Zustände ja fließend ineinander übergehen.

Bitte lesen Sie sich diese aufmerksam durch und legen Sie sie schnell greifbar in Ihrer Nähe ab, damit Sie bei Bedarf (Gedächtnisauffrischung) schnell wieder darauf zugreifen können.

(Z00) Skalen-Zustand 00 "gar nicht schläfrig": der Proband zeigt keine der unten erwähnten Anzeichen von Schläfrigkeit. Er erscheint dagegen hellwach und führt seine Fahraufgabe erkennbar aktiv aus (z.B. Scannen der Umgebung, regelmäßige Blicke in Spiegel und auf die Instrumente, etc.).

(Z01) Skalen-Zustand 01 "etwas schläfrig": Der Proband zeigt in diesem Stadium erste Erscheinungen von Müdigkeit/Schläfrigkeit. Grundsätzlich sind nur wenige der unten (Z02) aufgeführten Schläfrigkeitsmerkmale zu sehen (bzw. dies nur selten). Evtl. ist die aktive Teilnehme am Verkehr (wie bei Z00 beschrieben) eingeschränkt.

- weitestgehend normaler „Gesichtstonus“
- weitestgehend normales schnelles Blinzeln
- weitestgehend gewöhnliche schnelle Blicke
- gelegentliches Auftreten von Körperbewegungen und Gesten (siehe Z02)

(Z02) Skalen-Zustand 02 "mäßig schläfrig": der Proband zeigt möglichst mehrere bis alle der folgenden (wechselnden) Verhaltensweisen (sog. Manierismen):

- reibt das Gesicht und/oder die Augen
- kratzt sich
- verzerrt das Gesicht
- rutscht ruhelos auf dem Sitz herum
- u.ä.

Anmerkungen:

=> diese Verhaltensweisen können als Gegenmaßnahmen des Probanden zur aktiven Schläfrigkeitsbekämpfung angesehen werden.

=> sie treten in Zwischenstadien zur Schläfrigkeit auf

=> !!! nicht alle Probanden werden diese Manierismen aufweisen während des Übergangs vom wachen in einen schläfrigen Zustand zeigen, weshalb es sich nicht um zuverlässige Indikatoren handelt!!!

=> möglich ist auch ein eher "gedämpftes" Erscheinungsbild, charakterisiert von u.a.

- verlangsamten Augenlidbewegungen
- die Augenlider „hängen“ etwas, sind also dauerhaft ca. ein Drittel geschlossen
- abnehmendem Gesichtstonus/geringerer Durchblutung der Gesichtshaut/Blässe
- glasigen Augen
- Starren auf eine fixe Position

(Z03) Skalen-Zustand 03 "sehr schläfrig": der Proband zeigt möglichst mehrere bis alle der folgenden Verhaltensweisen:

- die Augenlider „hängen stark“ sind also dauerhaft ca. halb bis zwei Drittel geschlossen. Bei weiter zunehmender Schläfrigkeit (Bewertung dann >Z03) im Segment dominante weitgehende Augenlidschlüsse (Augen sind nur noch einen kleinen Spalt weit geöffnet.)
- längere vollständige Augenlidschlüsse von ≥2 Sekunden (Dauer & Anzahl notieren!)
- Aufwachreaktionen, z.T. mit Erschrecken
- Aufwärtsrollen/Seitwärtsbewegen der Augen
- stark reduziertes Fokussieren, Anschein, als schiele der Proband (die Blickvergenz nimmt stark ab)
- abnehmender Gesichtstonus/Gesichtsdurchblutung
- kaum noch sichtbare Aktivität
- weiträumige, isolierte Bewegungen (z.B. große korrigierende Lenkbewegung, Reorientierung des Kopfes, Korrektur einer schiefen oder gekippten Kopfposition...)

(Z04) Skalen-Zustand 04 "außerordentlich schläfrig": der Proband zeigt möglichst mehrere bis alle der folgenden Verhaltensweisen:

- einschlafen (z.B. verlängerte Aufwachreaktionen mit Desorientiertheit, o.Ä.)
- Aufwachreaktionen, z.T. mit Erschrecken
- ausgedehnte Lidschlüsse (> 4 Sekunden, mindestens 2 Ereignisse)
- ausgedehnte Perioden fehlender Aktivität
- große isolierte Bewegungen bei den Übergängen zwischen den Schläfrigkeitsintervallen (Eintritt in bzw. Austritt aus Schläfrigkeitsphase)

INFORMATIONSBLATT

Schläfrigkeit stellt eine der Hauptursachen für Unfälle dar. Das IAT und das Fraunhofer IAO haben ein System entwickelt, das Müdigkeit vorhersagen und entsprechend warnen kann. Die Effektivität dieses Systems soll nun in einem Versuch anhand einfacher Arbeitsaufgaben untersucht werden.

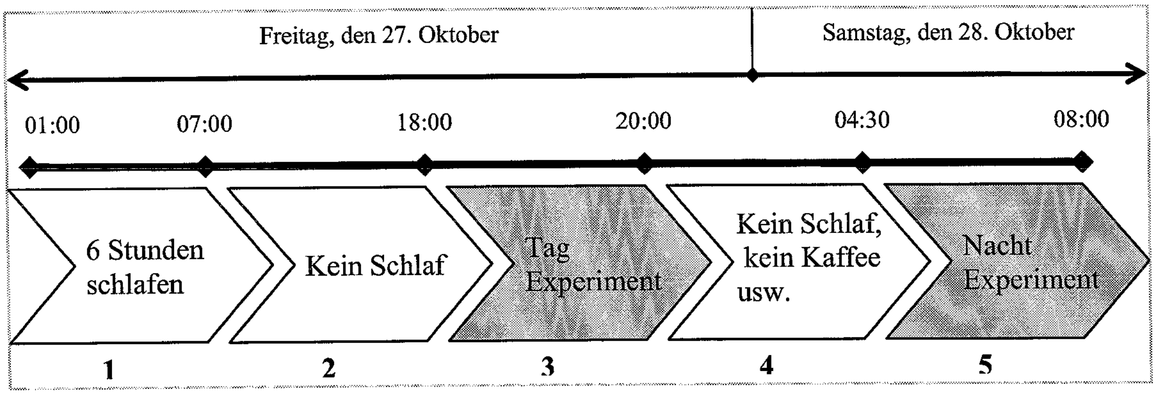
AUSSCHLUSSGRÜNDE

Aus Sicherheitsgründen dürfen Personen, auf die mindestens einer der folgenden Sachverhalte zutrifft, nicht an den Versuchen teilnehmen:

- Personen mit Erkrankungen des Gleichgewichtsorgans
- Personen mit Herzrhythmusstörungen / schweren Herzerkrankungen
- Personen, die stark blutdrucksenkende Medikamente einnehmen
- Epileptiker
- Personen mit Psychosen

VERSUCHSABLAUF

Schematische Übersicht:



1. Nur 6 Stunden schlafen

Schlafen Sie in der Nacht vor dem Tag-Experiment nur 6 Stunden. Gehen Sie um 1 Uhr ins Bett und stehen Sie spätestens um 7 Uhr wieder auf.

2. Zeitraum bis zum Tag-Experiment

Sie dürfen bis zum Anfang des Tag-Experimentes nicht mehr schlafen (von 07:00 bis 18:00). Bitte ziehen Sie für das Experiment Kleidung an die schmutzig werden darf.

3. Tag-Experiment

Das Tag-Experiment fängt um 18:00 Uhr an. Bei diesem Experiment wird Ihnen die Testaufgabe erklärt, die Sie für 10 Minuten zur Eingewöhnung proben. Anschließend folgt eine kurze Pause. Schließlich werden Sie nochmals 45 Minuten lang die Tests ausführen und Sie werden versuchen eine höchst mögliche Leistung zu erbringen.

Bevor Sie wieder gehen werden Sie mit einem *Actiwatch* ausgestattet. Dieses Gerät registriert ob Sie zwischen dem Tag- und dem Nacht-Experiment wach geblieben sind.

4. Zeitraum bis zum Nacht-Experiment

Sie müssen die Nacht im Fraunhofer Institut verbringen. Nehmen Sie in diesem Fall etwas zum Essen und Trinken mit. Nehmen Sie auch etwas mit, um die Zeit angenehm zu verbringen (z.B. ein Buch oder ein Laptop). Es gibt ein Computer mit einer Internetverbindung und ein Fernseher mit einem VHS-Videospieler die Sie benutzen dürfen. Für Videokassetten müssen Sie selbst sorgen.

Zwischen dem Tag-Experiment und dem Nacht-Experiment darf nicht geschlafen werden (von 20:00 bis 04:30 Uhr). Sie dürfen auch keinen Kaffee, schwarzen/grünen Tee, Cola-Getränke, Energiedrinks oder Alkohol trinken (Alternativen: z.B. Wasser, Früchtetee, Milch oder Saft). Falls Sie nachts einschlafen oder nachts/morgens Kaffinegehaltige Getränke / Alkohol trinken, geben Sie das bitte an. Dann muss der Versuch verschoben werden. Bei Verhinderung (z.B. durch Krankheit) sagen Sie bitte möglichst frühzeitig ab.

Bitte tragen Sie für das Nacht-Experiment wiederum Kleidung die schmutzig werden darf.

5. Nacht-Experiment

Das Nacht-Experiment fängt um 04:30 Uhr an. In diesem Experiment werden alle Tests wiederholt. Diese dauern nun 3,5 Stunden. Danach ist das Schläfrigkeits-Experiment zu Ende.

Wegen des Schlafentzugs ist es extrem gefährlich mit dem Auto, Motorrad usw. nach Hause zu fahren (Gefahr des Einschlafens). Bitte nutzen Sie den öffentlichen Personennahverkehr oder lassen Sie sich fahren.

Falls Sie noch Fragen haben können Sie immer Kontakt mit mir aufnehmen:

Pernel van den Hurk

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Einverständniserklärung

Mit meiner Unterschrift bestätige ich, dass ich freiwillig an den Versuchen zum Forschungsprojekt SENSATION teilnehme. Ich wurde über eventuelle Risiken und über Ausschlussgründe durch ein Risikoaufklärungsblatt aufgeklärt. Ich bestätige, dass keiner der dort beschriebenen Sachverhalte auf mich zutrifft. Insbesondere, bestätige ich, dass ich am Tag des Nacht-Experiments weder selbst als Fahrzeugführer zum Fraunhofer IAO fahre und noch, nachher selbst als Fahrzeugführer zurück fahre.

Ich stimme zu, dass ich alle Informationen über das erprobte Hypovigilanz-Management-System und den Versuchsablauf vertraulich behandle und ich sichere zu, dass ich hierzu keinerlei Informationen an Dritte weitergebe.

Mit der anonymen Verarbeitung und Veröffentlichung der während der Versuche erhobenen Daten bin ich einverstanden. Mir ist bekannt, dass die Versuche auf Video aufgezeichnet werden. Mit der Veröffentlichung der Videodaten bin ich einverstanden, soweit ich dies nicht im Folgenden ausschließe:

☐ Keine Veröffentlichung der Videoaufzeichnungen! (Bitte ankreuzen falls erwünscht!)

Mir ist bekannt, dass ich die Versuche ohne Angabe von Gründen jederzeit abbrechen kann.

Stuttgart, den __.__.2006

Name des Probanden

Name des Versuchleiters

Unterschrift des Probanden

Unterschrift des Versuchsleiters

Gebrauchstauglichkeit und Akzeptanz

Bitte bewerten Sie das Schläfrigkeitswarnsystem (Fachausdruck: Hypovigilanz-Management-System, HVMS) anhand folgender Fragen. Kreuzen Sie bitte jeweils die am Besten zutreffende Antwort an.

Das System soll später drahtlos (per Funk) betrieben werden. Versuchen Sie daher bitte, sich bei der Beantwortung die event. störenden Kabel "wegzudenken".

1. Allgemein

↙ sehr einfach — sehr schwierig ↘

1.1. Wie einfach/schwierig fanden Sie es, dieses HVMS zu bedienen? ① ------- ② ------- ③ ------- ④ ------- ⑤

↙ sehr einfach — sehr schwierig ↘

1.2. Wie einfach/schwierig fanden Sie es, die Funktionen dieses HVMS zu lernen? ① ------- ② ------- ③ ------- ④ ------- ⑤

↙ sehr einfach — sehr schwierig ↘

1.3. Wie einfach/schwierig fanden Sie es, die Funktionen dieses HVMS zu erinnern? ① ------- ② ------- ③ ------- ④ ------- ⑤

↙ sehr geholfen — sehr gestört ↘

1.4. Wie sehr hat dieses HVMS bei der Fabriksaufgabe geholfen/gestört? ① ------- ② ------- ③ ------- ④ ------- ⑤

2. Statusindikator (Grüne/Gelbe/Rote LEDs)

↙ sehr verständlich — nicht verständlich ↘

2.1. Wie beurteilen Sie die Verständlichkeit des Statusindikators? ① ------- ② ------- ③ ------- ④ ------- ⑤

↙ sehr zufrieden — nicht zufrieden ↘

2.2. Wie zufrieden sind Sie mit der Anzahl der Stufen des Statusindikators? ① ------- ② ------- ③ ------- ④ ------- ⑤

↙ sehr zufrieden — nicht zufrieden ↘

2.3. Wie zufrieden sind Sie mit der Anordnung der LEDs des Statusindikators? ① ------- ② ------- ③ ------- ④ ------- ⑤

2.4. Wie zufrieden sind Sie mit der Anzahl und der Größe der LEDs des Statusindikators?

↙ sehr zufrieden — nicht zufrieden ↘

① ------- ② ------- ③ ------- ④ ------- ⑤

3. Bedienung

3.1. Wie zufrieden sind Sie mit der Anordnung der Taster?

↙ sehr zufrieden — nicht zufrieden ↘

① ------- ② ------- ③ ------- ④ ------- ⑤

3.2. Wie zufrieden sind Sie mit den Größen der Taster?

↙ sehr zufrieden — nicht zufrieden ↘

① ------- ② ------- ③ ------- ④ ------- ⑤

3.3. Wie zufrieden sind Sie mit der Bedienkraft der Taster?

↙ sehr zufrieden — nicht zufrieden ↘

① ------- ② ------- ③ ------- ④ ------- ⑤

3.4. Wie zufrieden sind Sie mit der Rückmeldung des Systems auf einen Tastendruck?

↙ sehr zufrieden — nicht zufrieden ↘

① ------- ② ------- ③ ------- ④ ------- ⑤

4. Sprachmitteilung

4.1. Wie einfach/schwierig fanden Sie es, die Sprachmitteilungen zu verstehen?

↙ sehr einfach — sehr schwierig ↘

① ------- ② ------- ③ ------- ④ ------- ⑤

4.2. Wie zufrieden sind Sie mit dem Inhalt der Sprachmitteilungen?

↙ sehr zufrieden — nicht zufrieden ↘

① ------- ② ------- ③ ------- ④ ------- ⑤

4.3. Wie einfach/schwierig fanden Sie es, die Sprachmitteilungen zu erinnern?

↙ sehr einfach — sehr schwierig ↘

① ------- ② ------- ③ ------- ④ ------- ⑤

4.4. Wie oft sind Sie den Ratschlägen der Sprachmitteilungen gefolgt?

↙ immer — nie ↘

① ------- ② ------- ③ ------- ④ ------- ⑤

5. Auditive und vibrotaktile Warnsignale

5.1. Wie einfach/schwierig fanden Sie es, die Fabriksaufgabe auszuführen, wenn Warnsignale aktiviert waren?

↙ sehr einfach — sehr schwierig ↘
① ------- ② ------- ③ ------- ④ ------- ⑤

5.2. Wie einfach/schwierig fanden Sie es, wach zu bleiben, wann die Warnsignale aktiviert waren?

↙ sehr einfach — nicht schwierig ↘
① ------- ② ------- ③ ------- ④ ------- ⑤

5.3. Wie zufrieden sind Sie mit der Befestigungsstelle des Vibrationsgerätes Gerätes?

↙ sehr zufrieden — nicht zufrieden ↘
① ------- ② ------- ③ ------- ④ ------- ⑤

6. Bewegungsfreiraum

Bitte versuchen Sie, sich die Kabel "wegzudenken".

6.1. Wie beschränkend war die Befestigung dieses HVMS für Ihren Bewegungsfreiraum?

↙ sehr beschränkend — Überhaupt nicht beschränkend ↘
① ------- ② ------- ③ ------- ④ ------- ⑤

6.2. Wie zufrieden sind Sie mit der Formgebung dieses HVMS?

↙ sehr zufrieden — nicht zufrieden ↘
① ------- ② ------- ③ ------- ④ ------- ⑤

6.3. Wie zufrieden sind Sie mit den Abmessungen dieses HVMS?

↙ sehr zufrieden — nicht zufrieden ↘
① ------- ② ------- ③ ------- ④ ------- ⑤

6.4. Wie zufrieden sind Sie mit dem Gewicht dieses HVMS?

↙ sehr zufrieden — nicht zufrieden ↘
① ------- ② ------- ③ ------- ④ ------- ⑤

7. Akzeptanz

7.1. Wären Sie bereit, der Firma für die Sie arbeiten Zugang zu Ihren Daten über Erschöpfung und Müdigkeit auf Gruppenlevel (also z.B.: wie ist der Mittelwert der Schläfrigkeit der Gruppe) zu geben?

- ☐ Ja
- ☐ Nein
- ☐ Unsicher

7.2. Unter welchen Bedingungen wären Sie bereit, das HVMS zu benutzen?

- ☐ Um Ihnen Echtzeit-Kontrolldaten ihrer Erschöpfung und Schläfrigkeit zu liefern
- ☐ Um dem Arbeitgeber Echtzeit-Konrolldaten Ihrer Erschöpfung und Schläfrigkeit zu liefern
- ☐ Um im Fall von extremer Erschöpfung und Müdigkeit zu alarmieren
- ☐ Unter keiner Bedingung

7.3. Denken Sie, dass das HVMS in einer Fabrik für zum Erkennen von und zum Warnen vor Erschöpfung und Schläfrigkeit gebraucht wird?

- ☐ Ja
- ☐ Nein
- ☐ Unsicher

8. Bemerkungen

8.1. Wie war Ihre Motivation während die Fabriksaufgabe?

8.2. Was war Ihr Ziel während der Fabriksaufgabe, produzieren von vielen Einheiten oder vermeiden von Fehler?

↙ hohe Stückzahl kein Fehler ↘

① ------- ② ------- ③ ------- ④ ------- ⑤

8.3. Bitte beschreiben Sie, was Sie an diesem HVMS als besonders negativ empfunden haben:

8.4 Bitte beschreiben Sie, was Sie an diesem HVMS als besonders positiv empfunden haben: