PSYCHOLOGICAL RESPONSES TO NOISE AND VIBRATION

Jessica K Ljungberg

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O Herre, hjälp oss att utforska skapelsens hemligheter, cellernas valv och vintergatornas hieroglyfer, bevara oss från svindel vid denna branta kunskap, från högmod vid utvecklingens krön, så att världen blir alltmer genomskinlig och vi kommer allt närmare dig.

Ingemar Leckius
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ABSTRACT

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Vehicle drivers are a group of workers that are exposed to noise and whole-body vibration (WBV) several hours a day. Some drivers may also be exposed to high mental loads - monitoring and manipulating physical controls while engaging problem solving activities often with strong short-term memory and spatial manipulation components. Present standards and regulations that govern health risk assessment do not take into consideration the complexities of these multiple exposure environments. The effect of one factor (for example, noise or WBV) may be different than the effect of two factors presented together. This thesis investigates whether the combination of noise and WBV affects the performance of cognitive tasks more than when the exposures are presented separately.

A series of studies were designed to expose subjects to noise and WBV stimuli designed to simulate real life working conditions. Different combinations of subjective ratings, cognitive tests, and cortisol measurements were conducted both during and immediately after exposures, which ranged from 20 to 45 minutes. The results showed no combined effects on cognitive performance during or directly after exposure. However, the results showed significant higher ratings of difficulty and annoyance during combined exposures. Subjective noise sensitivity and cortisol (a biological indicator of stress) were not moderating factors. One study for noise exposure and one study for vibration exposure found that post-exposure degraded cognitive performance. In a study where participants were not required to perform any cognitive tasks during exposure, no differential after-effects were observed.

The studies have shown that a combination of noise and WBV do not degrade cognitive performance more than a single stimulus. However, WBV can degrade attention performance after exposure is turned off when drivers have been working under high mental load during exposure. The combined stimuli are also experienced as more annoying and work is more difficult in such conditions. The exposure times and task difficulty levels used in this thesis did not produce biological stress as measured by cortisol. Nevertheless, subjective ratings are sometimes seen as early indicators of other symptoms and with increased task difficulty and/or longer exposure times there may appear other measurable outcomes of the combined stimuli.

Keywords: Weinstein, Borg rating scale, cognitive, subjective, cortisol, performance
ORIGINAL PAPERS
This thesis is based on the following papers, which are referred to by their Roman numerals:


Aim

AIM

The specific aims with the studies included in this thesis are presented in the introduction. The overall purpose of this thesis is as follows:

- To determine what effects the combination of noise and WBV exposure has on cognitive performance, stress (measured by saliva cortisol), and subjective judgments.

- To focuses not only on effects that occur during exposure (Paper I and III) but also on what happens immediately after exposure (Papers II, IV, and V).

- To investigate the role stimulus level (Paper I) and self-reported noise sensitivity (Papers III and IV) has on cognitive performance, stress (measured by saliva cortisol), and subjective judgments.
INTRODUCTION

A heavy snow fell on the windscreen of the harvester as the operator tried to concentrate on finding the next tree to cut. The ground was frozen solid causing each jolt and shift of the machine to propagate into every muscle of the operator’s already tired body. The low, yet constant groan of the harvester had been wearing away at him since he started 12 hours earlier, causing him to feel numb. A mental exhaustion began to overcome him after a halfday’s total concentration on all the advanced manoeuvring required to operate the harvester and the quick decisions that continually have to be made to ensure the machine doesn’t stand still. He knew the harvester was an expensive investment and that it had to operate around the clock to be profitable. Thoughts raced through his head. Which tree next? Which one is the most profitable to cut. Does the harvester sound odd? Is it time once again to go out into the dark and cold to service it?

Tree harvesters, as described above and professional vehicle drivers must deal with noise and whole-body vibration (WBV) exposure. Noise and WBV in vehicle settings can be physically as well as psychologically demanding for the workers. The physical effects are well documented and have been extensively studied and are the bases of the international standards for noise and WBV that govern acceptable occupational exposure levels (ISO 1997a, ISO 1999). Although few studies have documented the effect of these exposures on mental performance, a few studies have examined how such environmental stressors negatively effect mental capacity (Sherwood and Griffin, 1990; Hygge, Boman, and Enmarker, 2003). If unwanted environmental stimuli physically interfere, overloading a driver’s mental capacity may negatively affect performance and may lead to a higher risk for injury or accidents; however, the regulations and standards that govern how to conduct health risk assessments for both noise and vibration environments do not consider any possible interactions between these two factors. The effect of one environmental stressor might be different when combined with another (Sommer and Harris, 1973; Howarth and Griffin, 1990a, 1990b; Nakamura et al., 1990; Paulsen and Kastka, 1995). The standards and regulations for work in certain tasks during exposure do not provide guidelines that address the effects of noise or WBV exposure on mental tasks (ISO 1997a, ISO 1999; ISO 1997b).
Introduction

Although it is fairly common for noise exposure to be the singular or most salient environmental stressor in many working environments, WBV exposure is almost always accompanied by equally significant amounts of noise. The effects of combined noise and WBV have not been extensively studied (at least not with regard to mental task performance); however, if there are combined effects and these two stressors interact, this should be considered.

Noise

Subjective experiences of noise
The World Health Organization (1980) defines noise, a subjective experience, as an unwanted sound. Because sound depends on who is listening and the person’s context, it is not feasible to define noise only in terms of physical parameters (Berglund and Lindvall, 1995). Guski (1997) defined noise as an environmental stressor causing displeasure and found that it has the quality to affect both health and well-being. The author also states that the term annoyance can be replaced interchangeably with subjective experiences as irritating or disturbing.

Participant’s ratings of noise annoyance have been found to correlate to other subjective experiences, such as ratings of loudness (Berglund, Berglund and Lindvall, 1975). Higher annoyance ratings were also found when people were working with mental tasks during exposure to a high frequency noise compared to when exposed to a low frequency noise (Key and Payne, 1981). These results, however, are inconsistent with what others have found (Persson Waye, Bengtsson, Kjellberg and Benton, 2001).

Lundquist et al., (2000) demonstrated that noise level is not an important factor when students rated their annoyance during exposure to a low frequency noise. Landström (1990), on the other hand, has demonstrated that noise with higher sound pressure levels at lower frequencies increase subjective judgments of alertness. Weinstein (1978) noted that some people have a personality trait that makes them more noise sensitive than others, a trait that may be invariant over different conditions and stable over time.
Introduction

Recent laboratory studies show that individuals who score high on noise sensitivity questionnaires have worse mental task performance than those who score low (Persson Waye, Bengtsson, Rylander, Hucklebridge, Evans and Clow, 2002; Belojevic, Öhrström and Rylander, 1992). However, Ellermeier, Eigenstetter, and Zimmer (2001), using signal-detection analyses, could not find any relationship between self-reported noise sensitivity and sensory inputs of auditory processing. Although participants in the high and low noise sensitive group had varied ratings of unpleasantness of the sound exposure, subjective noise sensitivity is more related to subjective judgments than perceptual components. Similarly, Miederna and Vos (2003) conclude that there is no clear relationship between noise exposure and subjectively rated noise sensitivity.

When investigating noise exposure and its role on performance and subjective judgments, it is important to not ignore the fact that a personality trait such as noise sensitivity (Weinstein, 1978) may confound the outcomes it is not controlled for. Subjective ratings were used (Papers I, III, IV, and V) and self-reported noise sensitivity was controlled for and applied as an inclusion criterion in Papers III and IV in this thesis.

Noise exposure and task performance
The effect of noise exposure on mental load has extensively been studied in many types of environments and experimental conditions. Outcomes may depend on the characteristics of the noise stimulus and the type of cognitive tasks performed. In addition to hearing impairments, noise has many other consequences that negatively influence a worker’s occupational load. The level and frequency of a noise can mask auditory information that workers need to perform their work safely and efficiently. For example, noise can mask an auditory warning signal (Crocker, 1997). Some studies, however, have found that masking can be positive. Exposing workers to multiple noise sources, for example, can reduce the influence of a distracting and isolated noise. That is, many noise sources tend to mask one another (Jones and Macken, 1995).

Many studies have examined more varied characteristics of level and frequency, such as the irrelevant speech paradigm. Some studies have noted the disruptive effect of irrelevant speech on short-term memory (Jones and Macken, 1993; Jones, Madden and Miles, 1992). In a review
Introduction

about human performance during noise exposure, Jones (1990) concluded that irrelevant speech strongly affects short-term memory performance as well as mental arithmetic, problem solving, and reasoning, all abilities that rely heavily on short-term memory. However, Jones (1990) concluded that it is the acoustic variation in the sound exposure that seems to be the important component, not the meaning of the speech. In a recent review article, Banbury et al. (2001) came to the similar conclusions about auditory distraction and short-term memory and that disruption depends largely on changes in pitch, timbre, or tempo as well as noise level does not seem to have much influence on performance. Hygge et al., (2003) and Enmarker (2004) confirmed these results using noise effects seen in other memory systems. These studies investigated the exposure of meaningful irrelevant speech and a road traffic noise on different memory systems. They found that a cued recall task that measured episodic memory degraded when subjects were exposed to these noise sources. Although the two auditory exposures seem quite different in acoustic structure, no differences were seen on the impaired memory performance between the two noise sources. These studies concluded that the negative performance, particularly in the cued recall tasks, was affected from both noises because of the change in the acoustic variation more than the speech or non-speech component. The results agree with other studies (Hughes and Jones, 2001; Jones et al., 1992).

Several studies have noted that cognitive performance decreases when people are exposed to a non-naturalistic continuous free field noise generated between 125-4000 Hz and played at 75, 78 dB(A), and 85 dB(C) (Smith, 1991; Smith & Miles, 1987; Smith, 1988). This type of noise negatively affects the performance of focused attention tasks (Smith, 1991), performance of a search and memory tasks with high memory load (Smith & Miles, 1987), and performance of a task measures the detection of repeated numbers (Smith, 1988).

In addition to the importance of the acoustic structure with respect to mental task performance, some researchers have found that the frequency of a noise can negatively influence mental performance. For example, a low frequency ventilation noise negatively affects cognitive performance: medium noise levels (58 dB(A)) decrease attention performances (Hygge and Knez, 2001) and rather low levels (40 dB(A))
Introduction

decrease performance on proof reading tasks (Persson Waye et al., 2001) and on verbal reasoning tasks (Persson Waye et al., 1997). Increasing exposure time performance further degrade performance because low frequency noise seems to be more difficult to habituate to compared to a predominantly mid-frequency noise (Persson Waye et al., 1997).

This thesis uses naturalistic noise stimulus that can be found in vehicle settings that have a typical low frequency character. The cognitive tasks used in this thesis are selected because they have proved to be sensitive to this type of noise and to WBV. A short-term memory task was used in Paper I, a verbal reasoning task in Papers III and IV, and a search and memory task in Papers IV and V. In Paper II, we used a mental rotation task to measure spatial ability because the spatial ability is an important mental capacity that may be under high load in many vehicle drivers’ environments.

Noise and biological effects
In the last 20 years, stress as measured by saliva and urine cortisol has received increased attention both in the field as well as in controlled laboratory settings. Study results have found positive correlations between self-reported experiences and cortisol response (Zeier, 1994). Van Eck, Berkhof, Nicolson, and Sulon, (1996) found that mood is a mediator between stressful events and increased cortisol secretions when performing daily activities. They found that small fluctuations in mood states during everyday events affects cortisol secretion, perhaps linking subjective experience to health outcomes.

Cortisol can measure stress when investigating noise exposure in field studies. For example, long-term exposure to industrial noise increases cortisol level (Melamed and Bruhis, 1996; Gitanjali and Ananth, 2003). In controlled laboratory settings, with shorter exposure time, cortisol influences the performance of participants playing a video game while exposed to music (Hébert, Béland, Dionne-Fournelle, Crete and Lupien, 2005). In addition, cortisol influences the performance of difficult arithmetic tasks while exposed to an intermittent background noise consisting of traffic, office, machinery, and unintelligible speech (Tafalla and Evans, 1997). Even exposure to moderate levels of a low frequency noise during performance of a logical reasoning task showed elevated
cortisol levels in subjects categorized as high noise sensitive (Persson Waye, et al., 2002). However, no effect on cortisol was found in a study using a simulated open-office noise with an exposure time of 3 hours (Evans and Johnson, 2000).

As cortisol seems to be a potentially sensitive tool to measure stress during noise exposure, it has been applied in this thesis (Paper III). Furthermore, because cortisol can impair memory functioning (Kirschbaum, Wolf, May, Wippich, and Hellhammer, 1996; Lupien, Gillin, and Hauger, 1999), a short-term memory was used to measure the effects of HKV and noise on cognitive performance. A more mentally demanding cognitive activity, a logical reasoning task, was also applied to encourage performance changes.

Whole body vibration
Transmitted through a vibrating surface, whole body vibration (WBV) can affect all parts of the body when sitting, standing, or lying down. In cars or trucks, where most people are exposed to WBV, the vibration moves from the vehicle through the seat and footrest all the way to the head, even causing the head to move. WBV can affect comfort, perception, and health (Mansfield, 2005).

Cognitive performances and the role of personality type
The relationship between WBV and cognitive task performance has not been widely studied. Most of the studies focus on mechanical interference of WBV, such as how people operate joysticks during exposure or how visual input is affected during different frequencies and levels of WBV (Kjellberg, 1990). A little more, but still not much, investigated is how WBV affects mental task performance while combined with other stressors. This will be discussed later. Sherwood and Griffin (1990, 1992) used a 16 Hz sinusoidal vertical WBV. The latter study investigated the effects on learning in the magnitude 2.0 m/s². Compared to a non-WBV group, the WBV group showed a decrease in an associative learning task. The other study by Sherwood and Griffin (1990) investigated effects on performance in a short-term memory task within the magnitudes of 0, 1.0, 1.6, and 2.5 m/s². They found an increase in response errors during only the 1.0 m/s². They found no support for the hypothesis that an increasing vibration magnitude generates greater
Introduction

decrement in cognitive performance. They suggest that the relationship is more complex although even low magnitudes of WBV seem to disrupt central cognitive functions when processing information in short-term memory.

Griffin and Hayward (1994) examined exposure to a fore-and-aft and a lateral WBV on reading speed and subjective ratings. When the fore-and-aft vibration was used, the reading speed was most impaired at 4 Hz with surrounding frequencies in the magnitudes between 1.0-1.25 m/s\(^2\). The lateral vibration showed a similar result, although to a less degree than the fore-and-aft vibration. The participants tended to overestimate decrement in reading speed. The authors concluded that the subjective estimates might depend on their impression of reading difficulty.

In addition to personality traits such as noise sensitivity, Webb et al., (1981) found that personality type might have a moderating role on performance during WBV. During exposure to WBV, people with an internal locus of control (people who give themselves credit for things that happens and have a more active personality) conducted fewer errors in a tracking task than people with an external locus of control (people who think they do not have any control over things that happen and have a more passive personality). In a more recent study, it was found that people that score high on a sensation seeking scale and thereby have a high need for novel, varied, and complex and intense experiences and emotional reactions tend to expose themselves to longer periods at higher intensities of vibration than people with low scores on sensation seeking personality scales. Although people with a high sensation seeking personality tend to expose themselves to higher intensities, this behaviour might lead to serious implications for a worker (Neely, Lundström, and Björkvist, 2002).

Subjective responses
In a review article about psychological aspects of WBV, Kjellberg (1990) concludes, compared to the corresponding noise studies, that there are few studies that address the subjective responses to vibration. Generally, these subjective studies about WBV conclude that doubling the vibration acceleration over a wide range of frequencies gives almost a doubling in subjective intensity, a result also true for subjective discom-
Introduction

fort (Dempsey et al., 1979). Kjellberg (1990) concludes that an individual’s subjective sensitivity to vibration depends largely on the frequency. This generally agrees with the findings that ISO (1997a) relies on, showing that a person is most sensitive in the frequency span of 4-8 Hz in the vertical direction (Z) and in the fore-and-aft and lateral (X and Y) direction in the span of 1-2 Hz. This effect has been shown to be true independent of acceleration level. Kjellberg (1990) also found that researchers generally agree that subjective discomfort increases with exposure time. Similarly, in a case-control study, Abbate et al., (2004) revealed that exposure time had a negative effect on emotions, such as fatigue-inertia, depression-dejection, and tension-anxiety. That is, extended exposure to WBV may be related to these kinds of negative emotions.

Few studies have examined the effects of WBV on subjective judgments, cognitive performance, and the role of personality type. The studies in this thesis rely on noise research about the moderating role of subjective noise sensitivity and its influence on performance in certain cognitive tasks. Unfortunately, there is no similar tool applied in WBV research.

Complex stressors

The effects of complex stressors on mental task performance were widely investigated during the 1970s. These studies show that when combining noise and WBV in different frequencies and levels, the interaction effect might not be simple, making it difficult to draw any general conclusions from these studies with respect to noise and WBV in different levels and frequencies and how they interact with performance outcomes. For example, these studies found that although a noise of 100-105 dB(A) when combined with a 5 Hz vibration (0.30 peak g) resulted in fewer adverse effects on tracking than with vibration alone (Grether et al., 1971; Grether et al., 1972;), a noise level that increases from 100 dB(A) to 110dB(A) combined with a 6 Hz (0.1, m/s²) vibration changed from a subtractive to an additive result (Sommer and Harris, 1973). Conversely, Harris and Schoenberger (1980) found a nearly reverse result: a 65 dB(A) noise stimulus combined with a complex sinusoidal vibration of 2.6, 4.1, 6.3, 10, and 16 Hz (0.36 m/s²) resulted in more adverse effects in a complex counting task than a 100 dB(A) noise
Introduction

stimulus combined with the same vibration. In addition, they found that a single 100 dB(A) noise and a single vibration stimulus negatively affected a counting task. Another study has also shown effects of just a single noise and a single vibration on performance in an arithmetic task, but this study failed to reveal any effects when both stimuli were combined (Sandover and Champion, 1984).

Although there are few studies about performance effects, there are more studies about the complex effects seen on subjective ratings. Manninen (1990) found that a noise stimulus combined with a 5 Hz WBV was generally rated more stressful than noise and WBV alone. In addition, Manninen found that sinusoidal vibrations at a resonant frequency were more stressful than a stochastic broadband vibration, and noise seemed to increase the experience of stress when the temperature was between 30°-35°C when combined with the stochastic broadband vibration.

The general findings from the investigations of perceived annoyance during exposure to an environmental naturalistic stimulus, such as noise or WBV, have been unanimous. A single stimulus should not be investigated separately since it has been found that one stressor interacts largely with the other (Howarth and Griffin, 1990a, 1990b; Nakamura et al., 1990; Paulsen and Kastka, 1995). Although there might be an interaction, it depends largely on the relative magnitude of the stimuli (Howarth and Griffin, 1990a, 1990b). The judgment of a vibration in the presence of noise decreases when the noise level is high and the vibration magnitude is low, which creates an antagonistic effect. A synergistic effect has been seen when both the noise level and vibration magnitude were high.

Noise and WBV exposure have also been investigated with a focus on physiological outcomes, and combined effects have been demonstrated on a number of parameters, such as palmer sweating (Sakakibara et al., 1989), temporary threshold shifts (Seidel et al., 1988; Seidel et al.; 1990; Manninen, 1983; Manninen, 1984; Manninen, 1986), and genotoxicity (Silva et al., 1999a, 1999b).

It is unclear, however, how noise and WBV interact. As mentioned earlier, few studies have examined the effects of WBV on cognitive per-
Introduction

This thesis examines how noise and WBV affects performance and subjective judgments both presented as a single stimulus as well as combined. Risk assessments should consider whether acute noise and WBV interact and negatively affects performance.

After-effects

Although many studies have examined the acute effects associated with noise and WBV, few studies have examined the after-effects associated with noise and WBV. After-effects are the effects that remain after the exposure to noise or WBV ceases. Perceptual after-effects include the sensation of ringing in the ears after operating a loud power tool and the sensation that the ground is moving after travelling on a boat or ship. In early studies, these sensations were understood using the adaptive-cost hypothesis: when a person is exposed to an environmental stressor (e.g., a continuous noise or vibration), the person will adapt to the stressors during exposure, but this adaptation can result in a cumulative cost, an after-effect (Cohen, 1980). Selye (1956) studied the biological costs of the adaptation and concluded that a long-term exposure to a certain stressor can limit the adaptive resources: as resistance decreases, fatigue increases.

Glass, Singer, and Friedman (1969) and Glass and Singer (1972) were two of the first studies that demonstrated an after-effect of noise exposure on mental task performance. These studies found that an after-effect can be reduced if the individual can control the noise source and if the noise has a predictable character. In the first of these studies, results also showed that the unpredictability of a typical urban sound was a more important factor for generating after-effects than the noise level. Evans and Johnson (2000) found similar results when using simulated noise from an office environment.

Cohen (1980) confirms Glass and Singer's (1972) results. An increase of control and predictability of stressors reduces negative after-effects on performance. Cohen also states that independent of predictability and control over stressor an after-effect can also be generated by high attention demands, and can be mediated by helplessness, which occurs when the individual is cognitively fatigued and fails to cope with the stressor. Cohen (1980) concludes that it is impossible that only one iso-
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lated stressor (such as noise) can cause behavioural after-effects alone. He assumes that multiple stressors cause after-effects.

The knowledge of a stressors after-effect on performance is most valuable in an applied perspective. For example, many vehicle drivers are exposed to noise and vibration for varied durations several times during a work shift. Any degradation in cognitive performance after the exposure during a driving shift might have direct negative consequences for the worker’s health or influence the task performance negatively depending on the types of activities that the workers participate in between or after a work-shift.

Kjellberg, Muhr, and Sköldström (1998) investigated noise exposure, fatigue, and performance. They found a relationship between work in noisy environments and increased complaints of headache and fatigue. Studying aeroplane mechanics and crews of ships in the coastal fleet, they found negative effects of high environmental noise exposure on reaction time when measured after a work shift. There were also some indications that the effect remained into the following day and caused a cumulative effect that was prolonged over a whole working week. Similar results have been found in another study by Lindström and Mäntysalo (1981). Workers’ reaction times were measured after exposure to a continuous industrial noise before, in the middle, and after a work-shift. The results indicated a trend towards a decrease in reaction time after being exposed to noise during the work-shift.

Tainsh and Winzar (1975) found negative effects on performance in an intellectual test (Watson-Glaser Critical Thinking Test) that was constructed to predict decision-making performance. The participants in the experimental group had undergone a 5-hour bus journey compared to a control group that conducted the test after a 5-hour normal working day without travelling. Twenty minutes degraded performance was seen in the experimental group after the journey compared to the control group. The authors did not discuss which factors in the journey might have contributed to the after-effect.

Degraded performance seen after exposure to a physical stimulus can be a risk factor. In many working situations when people are exposed to noise and WBV, they can maintain their performance during exposure,
Introduction

but may relax when it is turned off, such as after a work-shift. Because lowered performance in cognitive ability might cause accidents, this thesis investigated after-effects related to cognitive performance (Papers II, IV, and V).
MATERIAL AND METHODS

This thesis is based on five controlled laboratory experiments. The participants in all studies were students and recruited from a university population. Each participant was paid for their participation; all were in good physical health and tested for normal hearing. The local research ethics committee has reviewed and approved all the studies in this thesis.

A cross-modality matching method was used before the start of the studies in Papers I, III, and IV to match the sound levels of the noise stimulus with the chosen vibration magnitudes in subjective annoyance. The last study used naturalistic noise and vibration levels common in forwarders, and the stimuli were therefore not matched. For an overview of data collection methods used in this thesis, see Table 1 and for environmental stimuli see Table 2.

Short-term memory task
A Sternberg paradigm was used to measure short-term memory performance (Sternberg, 1966). For 1, 2, or 3 seconds, participants observed 2, 4, or 6 letters (respectively) presented on one line that was centred on a wide screen followed by a pause. For one second, a probe letter appeared and the task was to determine as accurately and quickly as possible whether the probe letter was part of a set of letters that was been seen earlier. Two thumb-operated response buttons, one marked YES and one NO, were used to register the responses. Reaction time and errors were measured as dependent variables.
Table 1. Methods used in paper I - V

<table>
<thead>
<tr>
<th></th>
<th>Paper</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
</tr>
</tbody>
</table>

Cognitive tasks

- **Short-term memory task**: ●
- **Mental rotation task**: ●
- **Logical reasoning task**: ●
- **Search and memory task**: ● ●

Subjective ratings

- **Stress**: ●
- **Annoyance**: ●
- **Difficulty**: ● ●
- **Intensity**: ● ●
- **Alertness**: ● ●

Noise Sensitivity Questionnaire

- **Saliva Cortisol**: ●

Mental rotation task

The mental rotation task was a computerized task that was applied to measure spatial ability. The commission consisted of three letters that were presented normally or mirrored and rotated in five positions (0°, 60°, 120°, 180°, and 240°). The participants’ task was to respond as fast as possible with two hand held response buttons, one marked “yes” and one “no”, if the letter was normal and rotated or mirrored and rotated. Reaction time and errors were measured as dependent variables.
Material and methods

Logical reasoning task
This task was a computerized Swedish translation of a grammatical reasoning task developed by Baddeley (1968). The participant is presented with a description of the relationship between the letters A and B and then asked to respond to whether a subsequent sentence describing the order between the pair of letters was true or false. The sentences could have both positive and negative structure. A positive sentence could read that A precedes B (AB) or B follows A (BA). A negative sentence could read B does not precede A (AB) or A does not follow B (BA). Reaction time and errors were measured as dependent variables.

Search and memory task
For the purpose of measuring attention performance, a search and memory task (SAM) was applied and conducted with paper and pen. Five target letters were presented in the beginning of a row of a random order of letters. The task was to memorize the target letters and then search for them among the following line of 59 letters. There could be 0-4 target letters on each line. The participants were instructed to search each row just once, to mark all target letters found, and to perform the task as fast as possible without missing any letters. Number of errors, speed (number of letters completed), and accuracy (percentage of missed targets) were measured as dependent variables.

Rating scales & questionnaires

Borg CR-10 rating scale
A Borg CR-10 rating scale was used for the subjective ratings in all studies except in Paper II (Borg, 1998). This scale applies verbal anchors combined with a roughly logarithmic numerical scale, ranging from 0 (nothing at all) to 10 (extremely strong). An “absolute maximum” is located outside the number scale to avoid ceiling effects. The participants first chose a verbal expression that best described their experience and then adjusted the response to the numerical scale (Appendix A).
Material and methods

Noise sensitivity questionnaire
For the purpose of measuring subjective noise sensitivity, a Swedish modified version of a Noise Sensitivity Questionnaire developed by Weinstein (1978) was applied. Other studies have used the same translated version (Persson Waye et al., 2002; Belojevic et al., 1992) (Appendix B).

Table 2. Environmental stimuli used in Paper I-V.

<table>
<thead>
<tr>
<th>Paper</th>
<th>Environmental stimuli</th>
<th>Control (Background noise)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Noise</td>
<td>Whole-body vibration</td>
</tr>
<tr>
<td>I</td>
<td>Helicopter</td>
<td>77, 81, 86 dB(A)</td>
</tr>
<tr>
<td>II</td>
<td>Helicopter</td>
<td>77, 81, 86 dB(A)</td>
</tr>
<tr>
<td>III</td>
<td>Forwarder</td>
<td>78 dB(A)</td>
</tr>
<tr>
<td>IV</td>
<td>Forwarder</td>
<td>78 dB(A)</td>
</tr>
<tr>
<td>V</td>
<td>Forwarder</td>
<td>72 dB(A)</td>
</tr>
</tbody>
</table>

Paper I & II

Participants
Fifty-four participants (27 men and 27 women) were recruited for a large data collection that resulted in Papers I and II. The mean age of the participants were 25 years, ranging from 19 to 30.

Experimental design
A mixed model design was applied using three groups of participants that were randomly and counter-balanced exposed individually to four environmental conditions: noise, whole-body vibration, both stimuli combined, and a control condition with no environmental exposure (in Paper II only the noise and the control condition were analyzed). Partici-
Material and methods

pants were also randomly and counter-balanced assigned to one of three intensity level groups.

Environmental exposures
The noise stimulus used in these two studies was emitted from a loud-speaker positioned 60 cm behind the participants and was continuously registered with an integrating sound level meter (Brüel and Kjær 2237).

In Paper I, a sinusoidal WBV was included in the design and it was generated vertically by means of an electrodynamics vibrator system mounted with a wooden seat plate. The acceleration level was continuously registered with an accelerometer (Brüel and Kjær 4368) that was connected to a sound level meter (Brüel and Kjær 2209). An overview of levels and character of environmental exposures are presented in Table 2.

Procedure
Although both Papers I and II rely on the same large data collection, they have the same procedure description. After being introduced to the task, rating scales, and procedure, the participants started the experiment with a short-term memory task (analyzed in Paper I) while being exposed to one of the four environmental exposures for 20 minutes (in Paper II only the noise and control condition are analyzed). While still being exposed, the participants subjectively rated difficulty, annoyance, and intensity. The ratings were followed by a 5-minute pause without any exposure. During this pause, a mental rotation task was performed for 5 minutes (analyzed in Paper II). This pattern continued until all four environmental exposures had been completed.

Statistical treatments
The statistical analyses was made using SPSS 10 and all data was analyzed with a variance analysis, repeated measure ANOVA’s.

Paper III & IV
Paper three and four consist of two experiments using two large data collections. One resulting in the data presented in Experiment 1 and the other in Experiment 2 for both studies. The participants used and the design applied is the same in both papers.
Material and methods

Participants
Experiment 1: Twenty-four men between the ages of 21 and 30 years old participated in this experiment.
Experiment 2: A high and a low noise sensitive group of male students were selected using the 30% lowest and highest scores in a Noise Sensitivity Questionnaire. Low Sensitivity group (n = 16, mean age of 24, SD 2.94) and High Sensitivity group (n = 16, mean age 23, SD 2.46).

Experimental design
Both studies applied a within subjects design where each condition was tested on a separate day and the order was randomized and counter-balanced over participants. The four environmental exposures were a single noise exposure, a single vibration exposure, a combined exposure of both noise and vibration, and a control condition with no environmental exposure.

Environmental exposures
An engineered low frequency sinusoidal WBV was generated in three different directions (in accordance with ISO 1997a). The frequency levels and proportions between the three directions were chosen to simulate those that are typically experienced by in a forwarder (a type of vehicle used in forest industry to pick up and transport cut logs) and were generated using a motion platform with a hydraulic set at 6-degrees of freedom. A driver's seat from a forest machine was mounted on the platform. A low frequency noise that had been recorded in the cabin of a forwarder during transport was also used. An overview of levels and character of environmental exposures are presented in Table 2.

Saliva samples (Paper III)
A Salivette sampling device (Sarstedt Inc; Rommelsdorf, Germany) was used to collect the saliva samples in Paper III. This method uses a cotton swab that participants chew for 90 seconds. After each collection, the samples are kept frozen until they are sent to a lab for analysis in accordance with the RIA method. The participants were tested the same time each day to avoid biases on the results although cortisol has a gradual circadian declining pattern during the day.
Material and methods

Procedure
On the first testing day, participants were given instructions and information about the tasks and procedure. They were also allowed to practice the cognitive tasks and underwent a hearing test. The procedure was the same for all the exposure conditions. The participants started the experiment with a rest for 30 minutes, which was followed by the initial saliva sample. The participants were taken to the experimental chamber. When the exposure to one of the environmental conditions had started, they performed a short-term memory task. After a pause, a logical reasoning task was conducted and when finished, a saliva sample was collected and the participants rated perceived stress and difficulty while the exposure was present. The total exposure time was approximately 44 minutes (SD = 4.3).

After exposure, the participants went to the room where they earlier had rested and completed the search and memory task and rated their alertness. On the fourth and final testing day, the participants completed the noise sensitivity questionnaire.

Statistical treatments
A three way repeated measures ANOVA and a Pearson’s correlation coefficient were applied using SPSS 11.0.

Paper V

Participants
This study included twenty-eight male participants between the ages 18 and 30 years.

Environmental exposures
This study used a simulated noise and WBV from a forwarder. The naturalistic WBV was generated through a driver’s seat from a forest machine that was mounted on a hydraulic motion platform with 6-degrees of freedom. The noise was the same stimulus as was used in Papers III and IV (Table 2).
Material and methods

Experimental design
The experimental design in this study was a within-subject design. The participants came to the laboratory individually on repeated occasions (the same time for three days in a row) and completed the search and memory task three times per day. Environmental exposures were arranged so that on one day the participants were exposed to a single vibration, on one day to a combined exposure of both noise and vibration, and on one day to a control condition with no environmental exposure. The participants were randomly assigned and counter-balanced to the exposure conditions.

Procedure
The first testing day started with the participants conducting a hearing test and they were instructed about the task and procedure. The experiment started with a 10-minute rest. Immediately after this rest, they conducted a search and memory task (SAM) (pre-exposure) for 4 minutes. During the 15-minute exposure to one of the environmental conditions, a movie recorded in the cabin of a lorry that was driven slowly on a light trafficked road was shown to the participants. After exposure (post-exposure 1), SAM was conducted a second time for 4 minutes. Afterwards, the participants had a 10-minute rest and then conducted SAM the last time (post-exposure 2) for 4 minutes. Subjective ratings of alertness, difficulty, and annoyance were collected during the test.

Statistical treatments
Repeated measures ANOVA and two-tailed Pearson’s correlation coefficient were used for the treatments of data applying SPSS 11.0.
RESULTS

Table 3 presents an overview of the statistical findings during and after exposure generated from the studies in this thesis.

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Results

Paper I

**Cognitive performance and subjective experience during combined exposures of whole-body vibration and noise**

No performance degradations were obtained in the short-term memory as the result of environmental exposure or level.

Participants rated the combined exposure condition of noise and WBV as both more annoying and more difficult to perform the short-term memory task compared to the single stimulus conditions and to the control condition.

The individuals in the highest intensity group rated significantly larger degree of annoyance than the individuals included in the lower intensity groups for all conditions.

Paper II

**Effects on spatial skills after exposure to low frequency noise**

Participants in the medium intensity group had significantly slower reaction time in the noise condition compared to the control condition. Analyses of errors showed no effect between conditions.

Paper III

**Stress and cognitive performance during exposure to noise and vibration**

No causal differences in the results were found between the High and the Low noise sensitive group seen in performance or in cortisol level.

The High noise sensitive group had elevated stress and difficulty ratings in the noise present conditions compared to the Low sensitive group.

The High noise sensitive group showed positive correlations in the noise exposure condition between elevated levels of cortisol and stress ratings. Positive correlations were also found between increased levels of cortisol and number of errors committed in the logical reasoning task.
Results

The High noise sensitive group had positive correlations between stress and difficulty ratings in all four conditions. Few correlations were found in the Low noise sensitive group.

Pooling data from both Experiments 1 and 2 showed a significant effect of noise exposure for rated stress and for rated difficulty. Participants subjectively rated higher stress and higher difficulty when noise was present compared to when not present. Higher ratings of stress and difficulty were also given when vibration was present compared to in the conditions when vibration was absent.

Paper IV

Cognitive after-effects of vibration and noise exposure and the role of subjective noise sensitivity

No effect was revealed between the two noise sensitive groups.

Pooling data from Experiment 1 and 2 showed a significant effect on accuracy and speed in the conditions when vibration had been present. The result showed that the participants had worked faster with less accuracy after exposure when vibration had been present compared to when not present.

Results revealed that participants had lower ratings of alertness when noise was present compared to when not present and higher ratings of alertness when vibration was present compared to when not present.

Paper V

Attention degradation after exposure to a simulated vehicle ride

No after-effect on performance was generated specifically by WBV.

An after-effect was seen as a lowered accuracy in the SAM immediately after exposure in all conditions.

An increased speed of searching letters in the SAM from pre-exposure to post-exposure 2 was found.
Results

Participants increased the speed of searching letters from pre-exposure to post-exposure 2 in the SAM in the combined and in the control condition. However, there was no increase in speed over time after exposure in the vibration condition.

There was a significant main effect of environmental exposures on rated annoyance. The participants had rated the combined and the vibration condition more annoying than the control condition. The combined condition was also rated more annoying than the vibration condition.

A main effect of environmental exposure on rated alertness was obtained. The participants had significantly higher ratings of alertness in the control condition than in the vibration condition.

The participants rated higher alertness pre-exposure compared to post-exposure 1 and 2.
DISCUSSION

Effects of complex and isolated stimulus

Cognitive measures
This thesis investigates whether the combination of noise and WBV exposure degrades performance in cognitive tasks more than when exposed to either noise or WBV. The studies included in this thesis failed to find any combined effects of noise and WBV on performance.

Tracking and counting tasks have been primarily used in studies that investigated effects of combined noise and WBV on mental performance. The results from these studies were inconsistent and showed both adverse and less adverse effects on performance when stimuli were combined compared to when presented alone (Grether et al., 1971; Grether et al., 1972; Sommer and Harris, 1973; Harris and Schoenberger, 1980). Because this research was largely focused on airplane pilot performance, the tasks chosen for study were geared to typical flight operations. In contrast, the tasks used in the present thesis tested more fundamental cognitive processes.

The studies applied a short-term memory task (Sternberg, 1966), a mental rotation task, a logical reasoning task (Baddeley, 1968), and a search and memory task measuring attention (Smith and Miles, 1987). Except for the mental rotation task that was used because spatial ability is a process that is much activated in many vehicle drivers working situation. The choice of tasks was based upon the fact that they had been found to be sensitive to exposure of either noise or WBV. For example, Sherwood and Griffin (1990) found that the short-term memory task was influenced by WBV; this task was used in Papers I and III. In Paper I, we used the same research method as Sherwood and Griffin (1990) with the exception that we used a helicopter noise as the sound stimulus. No performance effects were obtained. This suggests that the environmental stimuli used in Paper I did not provoke the participants enough to induce negative effects on performance based on type of environmental exposure alone.
Although the environmental stimuli used in this study were realistic (e.g., they were ecologically realistic), they contained no information that interfered with the task. The environmental stimuli were not in and of themselves salient enough to induce performance problems. A similar result was found in Paper III although the stimuli in Paper III had a more unpredictable and varied character than the noise stimulus used in Paper I. Similar noise has been shown to have negative consequences for performance in cognitive tasks during and after noise exposure (Jones, Madden, Miles, 1992; Glass and Singer, 1972; Cohen, 1980); however, the noise did not affect performance.

This result may lead to a better understanding of the effects of noise and vibration in the working environment. Many of these stimuli occur where motors and other machinery produce constant noise and vibration. The result seen here indicates that such exposures do not interfere with basic short-term memory functioning: neither vibration nor noise presented separately nor in combination affected short-term memory.

In contrast to the WBV research, short-term memory has been extensively studied during noise exposure. Researchers have found that noise exposure with a varied character with an acoustic change in pitch, timbre, or tempo (independent of speech or tones) has a strong relationship to serial recall in short-term memory (Banbury et al., 2001; Jones, Madden, Miles, 1992). These findings might also be of interest for applied research of the effects of WBV exposure and for investigations of more complex environments with both noise and WBV. Many working environments consist of changing noise and/or WBV such as those we used in Papers III- V. To apply a serial recall task might therefore be of interest for further research.

Effects on cortisol and the role of noise sensitivity

In Paper III, we investigated the effects on performance in the logical reasoning task and in the short-term memory task using saliva cortisol and subjective ratings during exposure to a single noise or WBV or from both in combination. It was predicted that performance changes were moderated by subjective noise sensitivity, and that exposure to either environmental stimulus presented alone or in combination would increase physiological stress measured in saliva cortisol.
Discussion

No effects on performance were detected. Neither the single stimulus nor the combined stimuli had any influence on the performance. One explanation of this result could be that the cognitive task used in Paper III was not sensitive enough for detection of any performance changes. However, Persson Waye et al., (2002) found that cortisol levels increased during exposure to a low frequency noise, and in the High noise sensitive group performance decreased when the group performed the same logical reasoning task as we applied. We found some indications in the first experiment in Papers III and IV that high noise sensitive subjects are related to elevated cortisol levels, to increased number of errors in the logical reasoning task (Paper III), and to increased accuracy in the search and memory task (Paper IV). These results led to Experiment 2 (Papers III and IV) where we used high and low noise sensitivity as inclusion criteria, but with the same research method as in Experiment 1. In Paper III, some indications in the High noise sensitive group were found. Results showed a positive relationship between increased cortisol levels and stress ratings as well as positive relationship between elevated cortisol level and increased errors in the logical reasoning task. Although we used a larger sample in Experiment 2 and thereby increased the power, no causal effects on performance in the cognitive tasks or in cortisol level were found between the two noise sensitive groups. Furthermore, interpretations of the correlations within the two groups may be limited by the fact that noise sensitivity scores were not in fact free to range throughout the whole scale because groups were determined using 30% highest and lowest cut-offs. In correlational analyses this is usually termed as a restriction of range problem.

In Paper III, one difference could be established between the High and Low noise sensitive group. The High noise sensitive group had elevated stress and difficulty ratings in the noise present conditions. This result agrees with the findings from the study by Ellermeier, Eigenstetter, and Zimmer (2001) who concluded that subjective noise sensitivity is more related to evaluations rather than to perceptual components. Similar conclusions have been stated in another study (Miederna and Vos, 2003).

We failed to find any causal relationship between subjective sensitivity to physical stressors and observed changes in saliva cortisol. It seems that the relationship between subjective judgments of sensitivity to physical stressors and observed changes is not simple. Carlson, Persson,
Karlsson, Österberg, Hansen, Garde, and Ørbæk (2006) could not find comparable changes in salivary cortisol levels that were related to self-reported stress among participants who were ecological sensitive to either electricity or smells. A similar result was found in another study by Hjortskov, Garde, Ørbæk, and Hansen (2004).

There are other studies that have found similar results as Persson Waye et al., (2002). These studies have proved that subjective rated noise sensitivity has an intimate connection to performance (Belojevic, Öhrström and Rylander, 1992; Jelinková and Picek, 1986). There are studies with similar outcomes as ours. For example, Zimmer and Ellermeier (1999), using a variety of subjective noise sensitivity measures, found only weak evidence of a link between noise sensitivity scores and objective performance (see also Ellermeier and Zimmer, 1997).

Some differences in the research methodology between our study and the study by Persson Waye et al., (2002) may account for the divergence. One such factor is the noise stimuli used in our study, which were qualitatively and quantitatively different. We used a naturalistic low frequency noise from an industrial vehicle whereas the noise stimulus in Persson Waye et al., (2002) was designed to reproduce a low frequency noise from a ventilation system in an office. It was also constructed to lift the low frequency components that are commonly associated with rated annoyance. Another discrepancy between Paper III and their study was that they had approximately an 80-minute longer exposure time and used both male and female participants. Although gender has not previously been found to be a significant factor affecting noise sensitivity scores (Weinstein, 1978), differences between male and females has been found in cognitive performance in different types of tasks (Lewin, Wolgers and Herlitz, 2001; Epting and Overman, 1998). Perhaps further studies could explore the role of gender with respect to noise and WBV and cognitive tasks.

It is also worth noting that there are studies that point out the importance of mood. Västfjell (2002) concludes that current mood (state) influences annoyance and that mood interacts with noise sensitivity (trait). Västfjell found that when low noise sensitive people have a temporarily low threshold because their mood is negative (more annoyed), they tend to give higher weight to their current mood. The high noise sensitive subjects tended to use their noise sensitivity (trait) as an
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evaluative base ("I’m sensitive to noise in general"), but the low noise subjects used their current mood as a reference ("For the moment, I’m annoyed").

Differences in ratings of annoyance between self-reported Low and High noise sensitive subjects can therefore be misleading. To control for current mood might be useful in further investigations.

After-effects
Post-exposure effects were investigated in both Papers II and III. An effect was seen on performance in the mental rotation task measuring spatial ability. This effect was only found in the group exposed to a medium level of a low frequency noise, but even though an identical design was used in the low and high intensity group, no effect was found in those. It was concluded that a personality trait such as noise sensitivity could have confounded the results. As discussed earlier, no causal effects between self-reported High and Low noise sensitive subjects have been found in the following Paper III and IV, so a noise sensitivity trait doesn’t seem to be responsible for this effect.

Paper IV examines whether exposures to noise and WBV constructed to reproduce a ride in a forwarder produce after-effects in subjective ratings of alertness and on performance in the search and memory task measuring attention. An effect of WBV was obtained showing degraded performance after exposures to the conditions where vibration was present. This result indicates a speed-accuracy trade-off after that vibration had been present. Participants worked faster at the cost of precision. Similar results have been found in studies that investigated effects during exposure and have applied a naturalistic traffic noise as a physical stressor (Hygge, Boman, and Enmarker, 2003). Paper IV presents new effects of WBV. The effects were quite small, but in many working environment even small effects can have significant consequences for the worker. One must also remember that the exposure time in this study was only three quarters to an hour, which is quite short compared to many working situations. The WBV level used was within the acceptable levels, by European standards, for an 8-hour working day and common in forestry vehicles such as forwarders. Although a large number of workers are exposed daily to whole-body vibration, a greater understanding of after-effects and how they may influence performance is warranted.
In Paper V, we examined the recovery time necessary before workers can perform normally again. The same research design was used as in Paper IV, but instead of performing mentally demanding tasks during exposure the participants watched a film that was recorded in a lorry that drove slowly on a lightly traffic road. Participants were rather passive compared to Paper IV. Degraded performance in the search and memory task was found immediately after exposure to all conditions: vibration only, vibration and noise combined, and a control condition without exposure. The effect did not last as long as after the 10 minutes of rest after exposure. A possible explanation to why no differences were found in the last study on accuracy between the exposures when vibration was present compared to when not present could be the type of task conducted during exposure. The effects on time-dependent accuracy in all conditions can be a result of inactivity, a passiveness that might produce fatigue, but this was only seen immediately after exposure. On the other hand, in Paper IV, there was a limitation of the cognitive resources after the vibration exposure was turned off and the demanding tasks were taken together. The unpredictable character of the WBV exposure was supposed to generate after-effects (Paper V) because those results were found after exposure to an unpredictable noise (Glass and Singer, 1972), but it did not show any influence on performance. Cohen (1980) concludes that in addition to unpredictable and uncontrollable noise a high mental load can degrade performance after exposure. It is therefore concluded that this result might have been different if the participants had a higher cognitive load during exposure, as was the case in Paper IV. The sum of an unpredictable stressor and a high mental load could thereby limit the resources more.

It should also be noted that most of the studies on WBV and its effects on cognitive performance have been focused on acute effects, and few studies have been conducted on long-term effects of exposure to WBV. Schneider and Wall (1985) have investigated this topic and found a relationship between long-term exposure to WBV and an increased risk for degraded attention.

Some vehicle drivers are exposed simultaneously to noise, WBV, and high mental load. Therefore, when a driver operates a vehicle that has a similar WBV and noise exposure as was used in Papers IV and V, during a exposure time not more than 40 min, negative effects on attention
performance can be found after they have been under high cognitive demand.

**Subjective judgments**

Subjective ratings have been applied in all studies in this thesis except for in Paper II. The subjective ratings complement the objective measures and make it possible to compare the outcomes between the objective and subjective measures. The combined effects of noise and WBV can be found in subjective judgments of annoyance and difficulty. The combined effect on annoyance ratings was seen independent of the character of the noise and WBV exposure. In Paper I, a predictable and naturalistic helicopter noise and an engineered predictable WBV in only one direction (Z direction) were used. In Paper V, there was an unpredictable complex WBV in three directions and a noise with a varied character; both stimuli were recorded in a for Swager during transport. The participant’s activity was also quite different in these studies. In Paper I, they performed a short-term memory task and in Paper V they were watching the film recorded from a driving lorry. Therefore, the type of stimulus (predictable or unpredictable) and type of activity during exposure do not seem to contribute much to the subjective experience of annoyance.

Higher ratings were also detected on stress and alertness. Participant’s rated higher stress in those conditions where a recorded noise from a forwarder played at a level of 78 dB(A) was present compared to when not present (Paper III). Higher ratings of alertness were also found in the conditions that included WBV (Paper IV); however, in Paper V reverse results were found. Participants were less alert after WBV exposure compared to after being in the control condition. These contradicting results might occur because the participants were activated during exposure in Paper IV, but in Paper V they were rather passive. The character of the work task during exposure seems to interact with the physical stimuli and this might be true for both subjective experiences of alertness as well as for effects on performance in the search and memory task.

In summary, combined effects of noise and WBV were found on subjective judgments of annoyance and difficulty, but could not be obtained on performance in cognitive task. Subjective judgments are sometimes seen as early indicators of other symptoms such as pain (Zhang, He-
lander, and Drury, 1996) and with increased task difficulty and/or longer exposure time, there may appear other measurable outcomes of the combined stimuli. For example, using a short-term memory task with a strong serial recall component has been found to be sensitive in noise research (Jones, Madden, Miles, 1992) and might broaden the knowledge of combined stimuli effects on performance. The noise in the studies included in this thesis are ecological realistic and it has been shown that these stimuli are not interrupting by themselves during the conditions used in this thesis. The mental task is therefore rather important for the outcome of measures and after-effects. More studies are needed that examine the combined effects of noise and WBV specifically as it relates to other cognitive systems. The results obtained in this thesis are also restricted to acute exposures with students as participants, moving the laboratory to the field would perhaps be fruitful. It is not likely that there are any large combined effects although the controlled laboratory studies in this thesis have failed to find even small tendencies.

The after-effect seen in degraded attention performance of WBV exposure is an effect that has never been demonstrated in other studies. This effect should be more thoroughly investigated because this could be a risk factor for people that work during such conditions. More research may also provide some insight into how our sensory systems work.

Remember our tree harvester from the beginning of the introduction? How can we apply the findings from the studies in this thesis on his working situation? First, one must conclude that independent of whether he is noise sensitive or not does not have any influence on his mental performance at work. However, in the real world it would probably be the case that he wouldn’t have continued with this occupation if he were highly sensitive to noise. The combined exposure of noise and WBV will not lower his mental capacity more than if he had been exposed to just one stressor. If he starts to experience his working situation as annoying, stressful, and difficult, the outcome after long-term exposure is hard to predict against the result obtained in this thesis. Let us remember that the knowledge we have is obtained from acute exposures and in the real world the working environment of a driver is much different: it consists of whole workdays during many years and effects may even be cumulative. We have seen that short exposures to WBV can have negative effects on attention performance and this may have implications for our three-harvester. For example, it may be important that after a
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working day with WBV exposure he will have to wait to recover before performing tasks that require his full attention to avoid mistakes or even accidents.
CONCLUSIONS

- A combination of noise and WBV does not degrade performance more than a single stimulus during or after acute exposures in some cognitive tasks.

- Subjective ratings indicate that combined stimuli conditions are experienced as more annoying and that work is more difficult in conditions where both noise and whole-body vibration is present.

- When measuring after-effects, the character of the work task during exposure seems to interact with the physical stimuli. This might be true for both subjective experiences of alertness as well as for performance in cognitive task, such as the search and memory task used in Papers IV and V.

- Self-reported noise sensitivity does not seem to be a moderator of performance changes in some cognitive tasks or of changes in saliva cortisol.

- Self-reported noise sensitivity can be a moderator of subjective judgments.

- Noise and WBV exposure within the research method used in this thesis are not connected to changes in saliva cortisol.

- Acute exposure to WBV can negatively affect attention capacity after exposure is turned off if a worker during exposure is under high mental load.
Fordonsförare är en grupp av arbetare som långa perioder varje dag under sina arbetspass är exponerade för både buller och helkroppsvibrationer (HKV). En del förare kan även ha en arbetssituation som kräver hög mental belastning, då de måste övervaka och manövrera många komponenter och reglage i de tekniskt avancerade fordonen. Detta kräver hög koncentration för att de ständig måste kunna lösa eventuella problem. Belastningen kan vara koncentrerad till uppgifter som kräver hög aktivitet i korttidsminnet eller på spatial förmåga då de manövrerar maskinen i olika terränger. De standarder och regelverk som finns idag tar dessvärre inte hänsyn till komplexiteten i dessa arbetsmiljöer. De beaktar bara påverkan ifrån en faktor åt gången, om buller och HKV tillsammans skulle orsaka en större negativ effekt på prestation än var för sig, så är det inte inbegripet i regelverken. Det övergripande syftet med denna avhandling var att undersöka om en kombination av buller och HKV kan påverka prestationen i kognitiva uppgifter, såsom uppmärksamhet, korttidsminne, spatial förmåga och logisk resonemangs- förmåga mer än vad dessa faktorer gör när de studeras var för sig.

En serie av studier genomfördes där deltagarna blev exponerade för buller och HKV som enskild stimuli men även i kombination. Samtliga studier var designade för att återskapa en verklig arbetssituation. Olika kombinationer av subjektiva skattningar, kognitiva test och stresshormonet kortisol mättes både under och omedelbart efter exponering. Exponeringstiden varierade mellan 20 och 45 minuter.

Resultaten av samtliga studier i avhandlingen visade inte några tendenser till kombinationseffekter på kognitiv prestation vare sig under eller efter exponering. Däremot upptäcktes kombinationseffekter på de subjektiva skattningarna av obehag och upplevd svårighet att utföra uppgifterna under exponering. Subjektivt upplevd bullerkänslighet, visade sig inte ha någon signifikant påverkan på utfallen. Inte heller upptäcktes någon effekt av buller eller HKV på stresshormonet kortisol.

Försämringar på prestationen i en uppmärksamhetsuppgift upptäcktes efter att deltagarna varit utsatta för en HKV. Prestationspåverkan verkar bero på en samverkan mellan att vara exponerad för HKV och samtidigt arbeta under hög mentalbelastning.
Svensk sammanfattning

Sammanfattningsvis har studierna visat att en kombination av buller och HKV inte har någon negativ påverkan på prestation i kognitiva uppgifter mer än om de skulle presenteras var för sig. Däremot upptäcktes kombinationseffekter på subjektiva upplevelser av obehag och upplevd svårighet av att utföra arbetsuppgifter under samtidig exponering för buller och HKV. Med den exponeringstid och svårighetsgrad på de kognitiva uppgifter som använts i denna avhandling, gick det däremot inte att se någon effekt på biologisk stress mätt med saliv kortisol.

Beträffande nedsättningar på uppmärksamhet av HKV exponering så är mer forskning önskvärd för att få en bättre helhetsbild av detta eventuella problem. Eventuella konsekvenser av HKV exponering bör dock tas under beaktande i de arbetssituationer som dessa finns, då denna typ av fysikalisk exponering kan ha en negativ påverkan på uppmärksamhet, i synnerhet då individen under exponering samtidigt utfört uppgifter som kräver hög mental belastning. I sådana fall kan HKV vara upphov till misstag i arbetet eller till olyckor.

Även om inga kombinationseffekter uppvisats på prestation i kognitiva uppgifter, så kan subjektiva skattnings ibland vara en första indikation på andra symptom som följer efter längre tids exponering. En uppgift med högre svårighetsgrad och eventuellt längre exponeringstider kan möjligtvis ge andra utfall av kombinerad exponering än de som uppkommit i dessa studier. Sannolikheten att upptäcka kombinationseffekter på prestation bedöms trots allt som små, då inte ens små tendenser har kunnat belysas i studierna i denna avhandling.
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så för att du hela vägen trott på och hjälpt mig till att bli en självständig fors-
kare.

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gav mig chansen att genomföra forskarutbildningen.

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önska sig. När det har känts motigt har jag tänkt på dig och då har allting gått
mycket lättare.

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kan verkligen lysa upp den grå vardagen.

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glada skratt.

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Mamma Alice, - t tack för all hjälp med barnpassning och assistans under den mest hektiska tiden under avhandlingsarbetet. Du är bäst!!

Min familj, Anders, Isak och Engla, - min dyrbaraste skatt, t tack för out-
trötligt stöd och kärlek.


References


References


References


APPENDIX A

Borg scale, CR-10

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<th>Value</th>
<th>Description</th>
<th>Swedish Equivalent</th>
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<td>Ingen alls</td>
<td>&quot;Ingen I&quot;</td>
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<td>Extremt svag</td>
<td>Knappt kännbar</td>
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<td>Lätt</td>
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<td>Stark</td>
<td>Tung Svår</td>
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<td>3</td>
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<td>11</td>
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<td>Absolut maximum</td>
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APPENDIX B

Noise sensitivity Questionnaire

<table>
<thead>
<tr>
<th>Datum:</th>
<th>Name:</th>
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För var och ett av följande påståenden ska Du ta ställning till om Du "instämmer" (helt, i stort sett eller delvis) eller "tar avstånd" (helt, i stort sett eller delvis). Tänk inte för länge utan ange din omedelbara reaktion!

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<thead>
<tr>
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<tbody>
<tr>
<td>Instämmer helt</td>
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<table>
<thead>
<tr>
<th>2. Jag är mer medveten om buller nu än jag varit tidigare.</th>
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<td>Instämmer helt</td>
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<tr>
<th>3. Möt för acceptera om någon har sin stereo på högsta volym ditt och ditt.</th>
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<td>Instämmer helt</td>
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<td>Instämmer helt</td>
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<th>5. Jag vaknar lått av buller.</th>
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<td>Instämmer helt</td>
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<tr>
<th>6. Om det är bullrigt där jag studerar, försöker jag stänga dörren eller stöttäcker eller skulle jag flytta mig någon annanstans.</th>
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<td>Instämmer helt</td>
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<th>7. Jag blir störd av buller från mina granmar.</th>
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<tr>
<th>8. Jag vanter mig vid de flusa (på sommar) avstånden.</th>
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<th>10. Även musik som jag normalt tycker om skulle störa mig om jag försöker koncentreras mig på något.</th>
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# Appendix B

<table>
<thead>
<tr>
<th></th>
<th>Instämmer helt</th>
<th>Instämmer i stort sett</th>
<th>Instämmer delvis</th>
<th>Tar delvis avstånd</th>
<th>Tar i stort sett avstånd</th>
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11. Jag skulle inte störas av att höra "vandgoljudd" från grannarna (förmig, rinnande vatten etc.).

12. När jag vill vara ensam, blir jag störtad av att höra ljud utifrån.


15. Jag har ofta behov av fullständig tystnad.


17. Jag har ofta det att koppla av på en bullrig plats.

